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MOTION DEVICES
*for Linear and Angular Oscillation
and for Abrupt Acceleration Studies
on Human Subjects (Impact)*

*Henning E. von Gierke
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**National Academy of Sciences –
National Research Council**

Publication 903

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MOTION DEVICES
for Linear and Angular Oscillation
and for Abrupt Acceleration Studies
on Human Subjects (Impact)

A description of facilities in use and proposed

A Special Report
by
Henning E. von Gierke
Eugene Steinmetz

for the Panel on Acceleration Stress
Armed Forces-NRC Committee on Bio-Astronautics

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National Academy of Sciences—National Research Council
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PREFACE

This report has been prepared under the auspices of the Armed Forces-National Research Council Committee on Bio-Astronautics, by the Panel on Acceleration Stress. The approved mission of the Panel is to review and report upon the research and development problems concerned with the biological effects of mechanical forces.

I wish to express appreciation to the representatives of the various organizations that have supplied the information on motion devices presented in the report. In most cases the descriptions of the devices and the illustrations were extracted from reports submitted to the Panel.

The report is designed to assist the investigator and the development engineer by placing before them a review of the present state of knowledge of the area, prepared by recognized authorities. It is with the hope that this initial review meets an immediate need of the Committee on Bio-Astronautics that it is forwarded by the Chairman of the Panel.

JAMES D. HARDY
Aviation Medicine
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INTRODUCTION

This report briefly describes the purposes, design principles, motion capabilities, and control and safety features of some forty facilities designed to study the effects of linear and angular oscillations and of abrupt acceleration on human safety and performance. Some facilities presently under study but not yet built are also included. Photographs or schematic drawings of the design are presented for those devices for which they are available. The report includes the geographical locations of the facilities and the contact point for obtaining further information on each.

The mechanical stresses to which operators and occupants of high-performance aerospace systems are presently exposed and will in the future be exposed make it imperative that information be obtained as to the various limits of man's safety, performance, and well-being under such conditions. Exploration under safe, well-controlled, and properly instrumented laboratory conditions of the physical, physiological, and psychophysiological causes limiting man's tolerance is desirable so that tolerance criteria for the design of the over-all aerospace systems can be established. The increase of man's tolerance by protective equipment, protective procedures, personnel selection and training, etc., is a further goal of such research.

For such laboratory studies, the total force-environment to which man is exposed has usually been divided into individual components such as sustained acceleration, impact, vibration, air-borne pressures, etc. The dividing lines have been established more or less by the availability of technical devices for laboratory simulation of certain components of the total force-time function; i. e., centrifuge research, research on vibration tables, impact research using sleds on linear tracks, etc. An illustration of ranges of time and acceleration obtainable with certain motion devices is presented in Figure 1 (after C. Clark). Frequently, the simplification has gone still further. For example, in vibration research most studies to date have been conducted using sinusoidal vibrations, mainly because devices producing random or programmed vibrations of large enough amplitude have not been available. There is no doubt that this type of approach has its merits; methodical separation of the important physical parameters brings clearer insight into the basic mechanisms influencing the organism. On the other hand, it

is justified from a practical point of view only if finally the components are put together again and a reaction to the over-all complex force-environment is studied with a broad understanding of the action of each individual component.

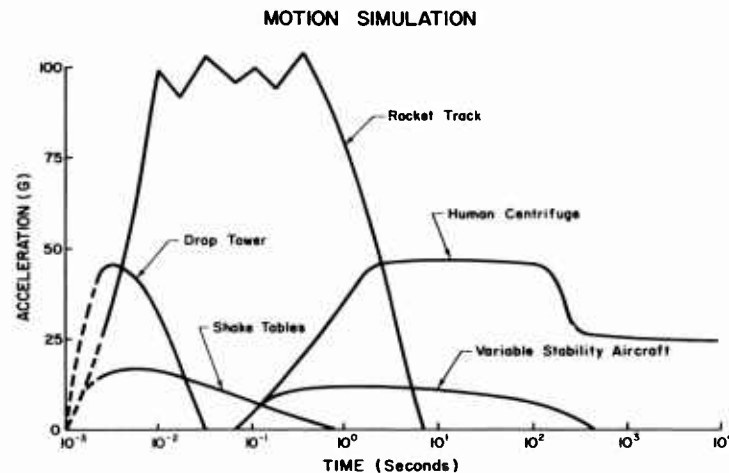


Figure 1. Ranges of time and acceleration obtainable with certain motion devices (after C. Clark)

It should be obvious from the preceding remarks that a wide spectrum of motion devices of various degrees of complexity is necessary to fulfill the requirements of a basic and applied research program in biodynamics. Motion devices producing relatively simple motion patterns not representative of actual environments are probably better referred to as physiological research tools. Their capabilities should definitely exceed the motion-range anticipated for operational conditions. They should be built to explore the absolute limits of man's tolerance and to exhaust protection possibilities. Closed-loop operation is usually not necessary for such devices. The more complex devices designed to simulate the complete actual environments are better referred to as motion simulators. They should simulate as realistically as possible all motions of the operational vehicle. These devices are actually "flown." Closed-loop operation is usually mandatory, but the motion levels will for the most part be smaller than in the first type of devices. Naturally a clear cut separation between these two categories is not possible.

The purpose of the present report is to describe only those motion devices which have been used to study the responses of humans subjected to oscillating linear or angular accelerations, and

to impact. If it is desired to obtain a complete picture of our present capability to produce the acceleration environments anticipated in space flight in the laboratory, the report should be read together with the other reports on centrifuges, multi-degree-of-freedom flight simulators, and rotation devices prepared under the same project. The following report gives a brief description of the purpose and design of each motion device and its capabilities. An attempt has been made to include all information of interest:

- a. To obtain an over-all view of present capabilities.
- b. To decide if a particular device would be helpful in the solution of a particular acceleration problem.
- c. To indicate to planners and designers of new devices the principles and limitations of available facilities. (In each case the point of contact for obtaining more detailed information is listed.)

It is realized that for some devices the description or the performance data are sketchy and incomplete. The short time available for this project made it necessary for the authors to depend on the information voluntarily supplied by the various organizations involved; further, in several cases a re-check with the organizations revealed that the exact performance limits or motion capabilities were not or are not yet known to the operator of the device. This survey has established clearly the desirability of publishing a separate report on the design and evaluation of each major new motion device.

Motion capabilities which do not clearly fall under this report --for example, the oscillation capabilities of centrifuges or of variable stability aircraft--have been included only for completeness. In such cases emphasis has been put on the motion capability of interest in connection with this report, and no complete description of the device has been attempted. Some equipment not used for subjecting man to vibrations but used in general oscillating-motion research; for example, the horizon projector has also been included.

In general, only devices built specifically for human factors research and which have been used for this purpose are listed. Most of these devices have available some or all of the medical and instrumentation facilities necessary for such research. Only a few devices are listed which have been used for animal, dummy, or equipment tests rather than for tests on humans. In most cases they are listed because of their potential interest for experiments using human subjects.

A brief survey of the characteristics of most of the devices described is presented in the summary chart on oscillation and impact devices which appears at the end of this book. A few devices dependent on parameters too numerous to mention in a table have been omitted from this presentation, but are included in the body of the report.

The reader interested in the state-of-the-art of vibration and impact research is referred to a recent review article on this subject with an extended bibliography.¹

A few general conclusions which resulted from this survey are as follows:

1. Although new motion devices with higher capability are desired and technically possible today, human factors research in this area has not been seriously hampered by the non-availability of facilities. On the contrary, in many cases it is surprising how little use has been made of and how few research results are available from relatively expensive facilities. In many places personnel to conduct a productive program have been available only on a temporary basis.
2. Devices for simulating and studying tolerance to the following acceleration loads are practically non-existent, although such loads must be expected in future aerospace operations:
 - a. Angular oscillations
 - b. Random oscillations in several degrees of freedom
 - c. Multiple-impact patterns; i. e., impact with multiple rebound

Several of the proposed facilities included in the report would fill these requirements.

3. The lack of data as to the vibration and impact levels present and to be expected in the actual flight environments is a bottleneck in planning new facilities.

1. Goldman, D. E. and von Gierke, H. E. "The Effects of Shock and Vibrations on Man" Lecture and Review Series No. 60-3 Naval Medical Research Institute, Bethesda, Maryland, 1960.

4. Although a few facilities for the study of other stresses have limited motion capabilities, high-performance oscillation and impact devices which allow combination of acceleration stresses with other environmental stresses are practically non-existent.

5. It is desirable that a separate report with complete design and performance data be issued as early as possible on each major new motion device.

1. VERTICAL ACCELERATOR (Wright Air Development Division)

Introduction

The vertical accelerator was built by the L. A. B. Corporation of Skaneateles, New York. The purpose of the device is to study the effect of low-frequency, high-amplitude vertical vibrations on the biodynamics, physiology and performance of subjects. The machine can be programmed with random or periodic vibrations and transient acceleration patterns to simulate the buffeting environment of re-entry missions or of high-speed, low altitude flight.

Description

(See Figures 1-1 and 1-2) The machine employs a friction drive between a 30-ft. high driving cylinder and a carriage subjected to the vibrations. The carriage receives power from the cylinder through twelve pneumatic tires. While the cylinder (24 inches in diameter) is rotating at constant speed (300 rpm), the servo-system controls the axis of the tires relative to the axis of the cylinder. As a result the carriage moves in the direction in which the wheels are steered. The rate at which the wheel direction is changed controls the acceleration of the carriage. This acceleration is determined by a previously selected program and is executed through the servo motor with its amplifier system. Within the frequency, amplitude, and acceleration limitations of the machine the carriage follows any complex acceleration pattern selected. Hydraulic pressure is used to engage the tires with the cylinder and simultaneously to release the mechanical brakes. An auxiliary vibrator is provided on the carriage to supply sinusoidal vibrations of higher frequencies to the platform of the carriage. The total weight of the carriage cannot exceed 2,000 lbs., which allows approximately 400 lbs. for experimental seat and subject. The subject is seated in such a way that accelerations are produced on the subject's body parallel to his spine.

Motion Capabilities

The vertical accelerator was designed for operation with a complex acceleration-time pattern over the frequency range 0.3 to 10 cps. Its amplitude is limited to ± 10 ft., and its acceleration to

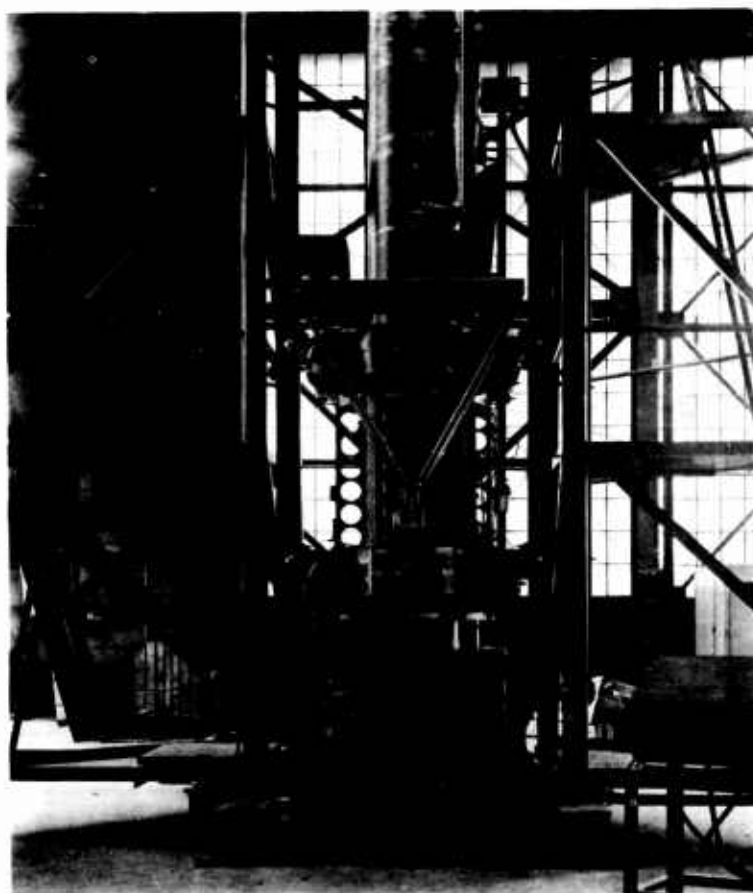


Figure 1-1. WADD Vertical Accelerator

approximately $\pm 3g$, however, modification of the tire design may extend this maximum acceleration capability. The auxiliary vibrator shakes the platform in addition to the low frequency vibrations with sinusoidal vibrations adjustable between 10 and 20 cps. and adjustable amplitude up to 0.12 inches. The frequency response of the vertical accelerator is presented in Figure 1-3.

Control System

The servo control system, which is an open-loop system, of the accelerator is designed to give full response to an electrical input signal of ± 50 volts. The control panel allows switching of the input to a signal generator, a random noise generator, a magnetic tape playback, or a 35 mm. film reader. Closed-loop operation of the machine is possible in principle and planned for the future.



Figure 1-2. WADD Vertical Accelerator:
carriage with platform and seat.

Safety Features

The vertical accelerator is equipped with several safety features which include electrical limitation of the input signal, an amplitude-limitation switch on the cylinder, which is operated mechanically if the carriage exceeds preset limits, an automatic reduction of wheel angles to zero position, giving zero vertical velocity when the carriage approaches upper and lower end positions, spring-actuated safety brakes in case of power or hydraulic failure, emergency shock absorbers at the two end positions reducing the maximum shock to 20 g's for a free fall of the platform from a 15-ft. height, and a signal button and intercommunication system for test subject on the carriage.

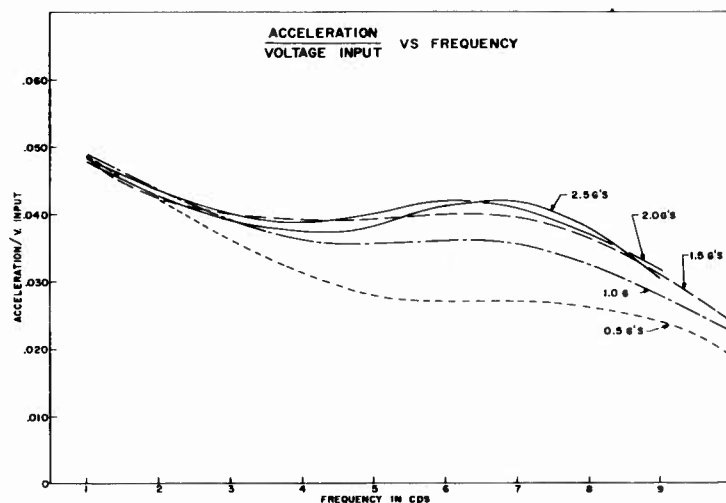


Figure 1-3. WADD Vertical Accelerator: Frequency response in platform acceleration per volt input.

Information

For information contact Dr. H. E. von Gierke, Chief, Bio-Acoustics Branch, Aerospace Medical Laboratory, Wright Air Development Division, Wright-Patterson Air Force Base, Dayton, Ohio.

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2. Von Gierke, H. E., "Vibration and Noise Environment of Missiles and Space Vehicles," Noise Control, May 1959.
3. Roman, J. A., Coermann, R. and Ziegenruecker, G., "Vibration, Buffeting, and Impact Research," Journal of Aviation Medicine 30 (118), 1959.

2. U. S. ARMY MEDICAL RESEARCH VIBRATOR (Army Medical Research Center, Fort Knox, Ky.)

Introduction

The U. S. Army Medical Research Vibrator is an electromagnetic force generator made by the MB Manufacturing Company. The device has been built for the purpose of physiological performance studies.

Description

(See Figure 2-1) The device consists of a Model C25B Vibration Excitor and a Model T51MCB Control Cabinet.

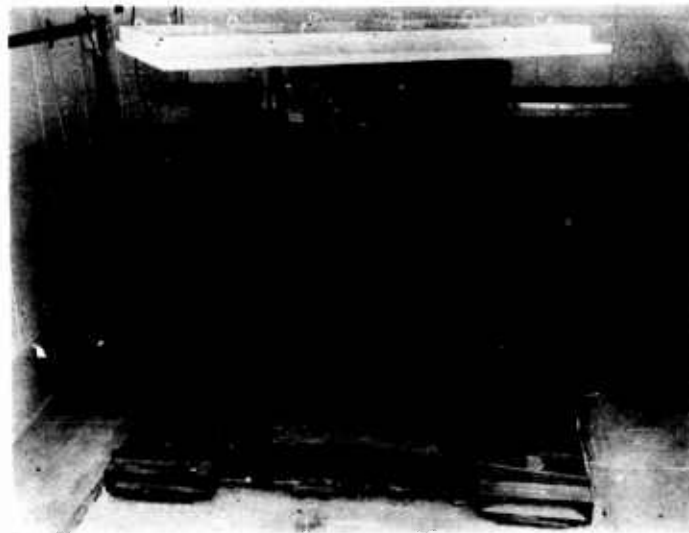


Figure 2-1. U. S. Army Medical Research Vibrator.

Motion Capabilities

The device will provide a maximum displacement (double amplitude) of 0.5 inches. According to company specifications, frequency may be varied from five cps. to 2,000 cps. The unit will deliver 3,500 lbs. vector force. Test specimens up to 300 lbs. can be handled without external support.

As frequency is increased, the displacement obtainable is reduced. The maximum displacement obtainable at any given frequency depends on the weight of the object on the vibration table. Accelerations up to 10 g are possible with a 280-lb. table load; 20 g with a 100-lb. load.

Table motion is sinusoidal. Both vertical and horizontal vibrations are possible (one at a time).

Control System

Details pertaining to the control system and safety features are not available.

Information

For information contact Dr. Floyd A. Odell, Technical Director of Research, U.S. Army Medical Research Laboratory, Fort Knox, Kentucky.

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1. Loeb, M. "A Preliminary Investigation of The Effects of Whole-body Vibration and Noise," AMRL Report No. 145, Fort Knox, Ky., 1954.
2. Schaefer, V., Link, H., Farrar, J., and Wiens, D. "Lethality in Rats as a Function of Frequency in Constant-displacement Vibration," USAMRL Report No. 390, Fort Knox, Ky., 1959.

3. NORTH AMERICAN AVIATION DYNAMIC FLIGHT SIMULATOR (North American Aviation, Inc., Columbus, Ohio)

Introduction

The vastly increased spread between minimum and maximum operating speeds and altitudes of modern high performance aircraft has produced many flight-control problems. Investigation and solution of these problems by flight-test programs alone has become an extremely expensive and time-consuming process. Each performance increase in aircraft has emphasized the need for a realistic flight simulation to supplement the flight-test program. Such simulation is available by means of the N. A. A. Dynamic Flight Simulator which consists of a vertically-oscillating seat capable of experiencing "g" forces corresponding to those of the aircraft being simulated. Additional illusion of flight is provided by optical presentation and seat environment.

Description

(See Figure 3-1) The basic physical components of the Dynamic Flight Simulator are: the motion simulator (seat canopy moving on vertical tracks), projection screen, and a slide projector, a computer and tape complex, and a functional aircraft mockup.

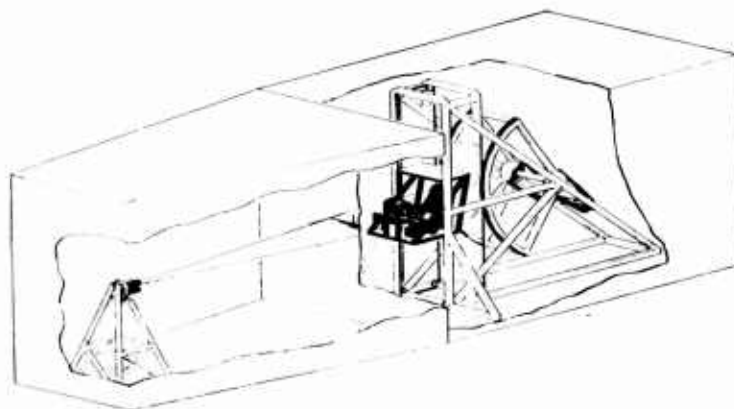


Figure 3-1. North American Aviation Dynamic Flight Simulator: Motion simulator with projector and screen.

The pilot's seat, shown in Figure 3-2, is of metal construction three feet wide, four feet high, and four feet deep with expansion capabilities to seven feet deep. The seat is mounted on a light-weight frame which is enclosed to restrict the pilot's view to the projection screen area. This seat frame includes flight-control systems from stick and rudder pedals through the command potentiometers and artificial feel bungees. A dummy instrument panel is also installed.



Figure 3-2. North American Aviation Dynamic Flight Simulator: Seat canopy.

The seat-canopy assembly, shown in Figure 3-3, is moved vertically by a dual closed-cable system. The two cables stabilize

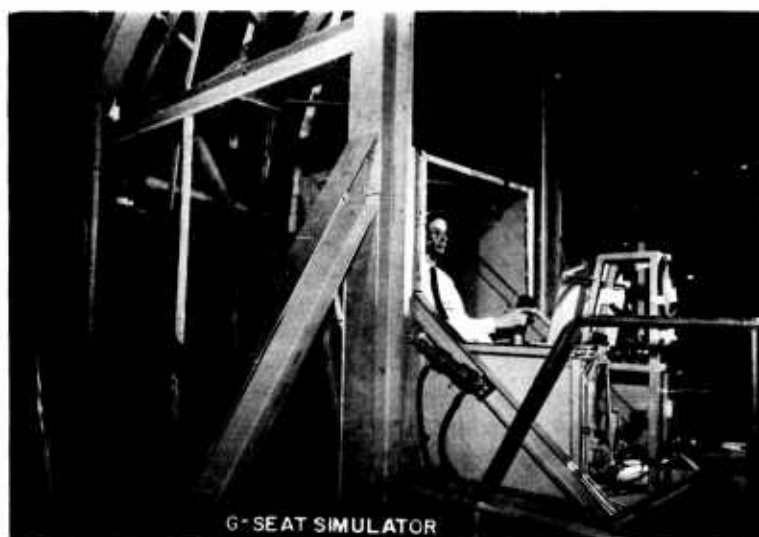


Figure 3-3. North American Aviation Dynamic Flight Simulator: Seat canopy.

the seat laterally and four rollers running in tracks stabilize it in the longitudinal axis. The cables are attached to a light-weight eighty-one-inch radius sector which is driven through a displacement of ± 55 degrees by four linear hydraulic actuators operating on a thirteen-inch radius. Control of these actuators is provided by a hydraulic servo valve with a linear motion potentiometer supplying the seat position followup.

The screen, which is located seven feet forward of the pilot, is a twelve by eighteen-foot translucent rear projection screen. Low-intensity blue lights behind this screen give it the appearance of blue sky.

A 500-watt 35-mm slide projector, shown in Figure 3-4, is mounted on a three-axis rate table. This table is driven in pitch and roll by vane-type rotary hydraulic actuators. The yaw is driven by a linear hydraulic actuator. All three actuators are controlled by hydraulic servo valves. Each axis has a linear-motion potentiometer for position followup.

Motion Capabilities

The seat is capable of moving (vertically only) a man weighing 200 lbs. and having a sitting height of 40 inches through an amplitude range of ± 5.5 ft. The maximum velocity is 9.0 ft/sec. and the

maximum acceleration is ± 2.0 g's. The frequency response is shown in Figure 3-5. The response is essentially flat out to 2.0 cps., and drops to three db. at approximately 2.8 cps.

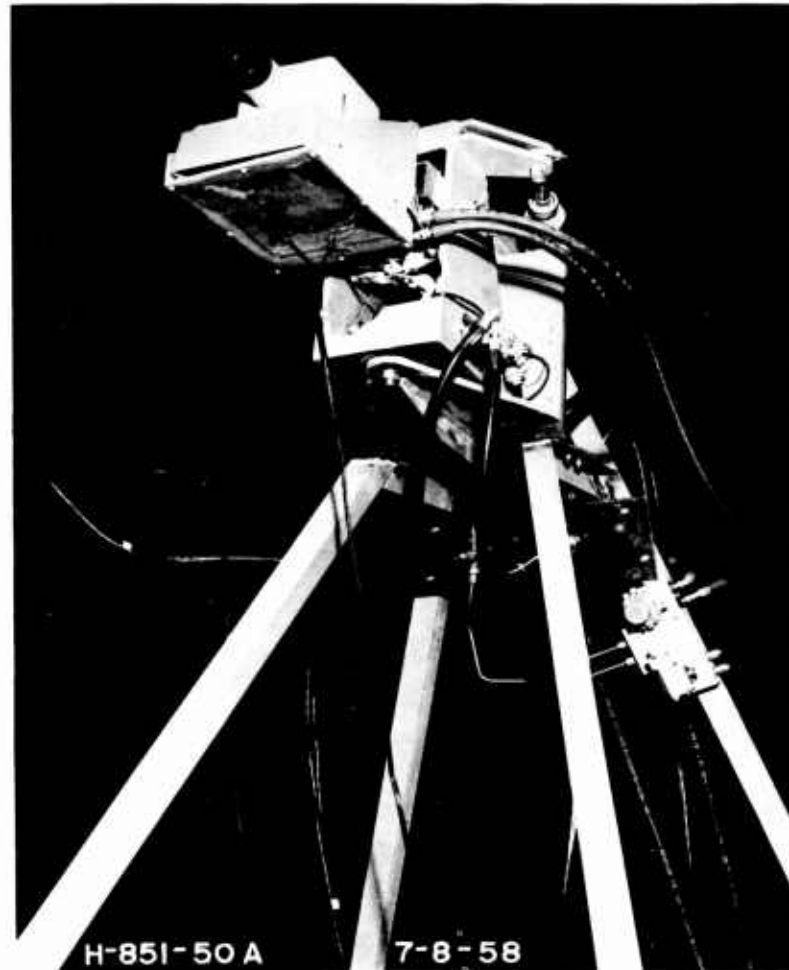


Figure 3-4. North American Aviation Dynamic Flight Simulator: Slide projector on pitch roll and yaw table.

Control System

The control system is a position-type control. The simulator is capable of both open and closed-loop operation. For open-loop operation the control input to the seat is through a magnetic tape or computer. For tape input, either position or acceleration tracings are usable. For closed-loop operation, the control input to the seat

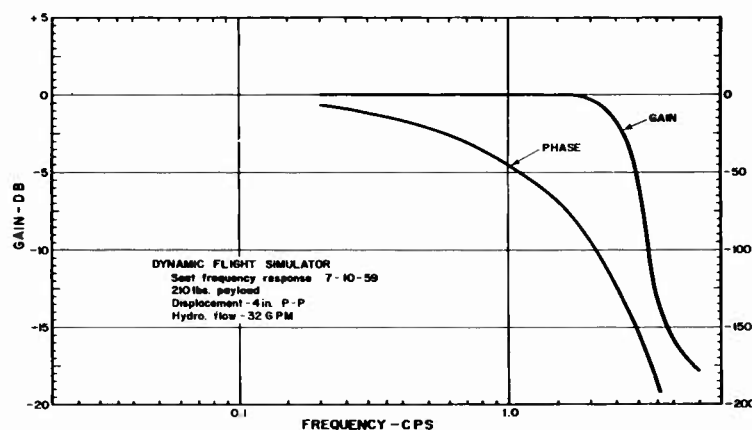


Figure 3-5. North American Aviation Dynamic Flight Simulator: Seat frequency response.

includes both tape computer and subject manual inputs. Subject manual inputs are via conventional stick and rudder pedals. These manual inputs are transformed to electrical signals and are fed to the computer for both aerodynamic and flight control transformations. The signal is then fed back to the drive mechanism for seat positioning. Control of the projector position is either via independent magnetic-tape signal source or via computer. In both situations the control signal is of a position of the pitch, roll, and yaw dimensions.

A general purpose analog computer is used to simulate the aerodynamic equations of motion and the various control systems of any given aircraft. The aircraft can be simulated at any flight condition. Electrical inputs from stick and rudder pedals enter the computer via the functional mockup. These signals are acted upon by the aerodynamic equations which then send a relative signal to position the seat. For roll and yaw, the operation is essentially the same with the exception that the computer signal which is the electrical analog of the airplane response is fed back into the three-axis projector table instead of the seat.

Safety Features

Several features are incorporated into the Dynamic Flight Simulator to provide for the safety of the seat occupant and mechanism. Among these are: A relief valve in the seat-drive hydraulic actuators which limits the acceleration, an electronic limiter in the computer which stops the signal input as the seat

nears the end of its maximum displacement, mechanical spring stops which are installed at the top and bottom of the frame to dampen the possible contact by the seat cage, a shoulder and lap-belt type harness provided to properly restrain the subject in the seat, and an inter-communication system in the seat which provides instantaneous speaking contact with all seat operators.

Information

For information contact G. R. Gerkens, Chief Engineer, North American Aviation, Inc., Columbus Division, Columbus 16, Ohio.

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1. Williams, J. W. and Rossing, R. J., "N. A. A. Dynamic Flight Simulator," Report number NA58H-509, December 20, 1958.

4. LARGE DISPLACEMENT-AMPLITUDE VIBRATION MACHINE (Naval Medical Research Institute, Washington, D. C.)

Introduction

In order to study some of the physiological effects of mechanical vibrations on man, a direct-drive mechanical vibration machine, capable of providing large sinusoidal vertical displacements, has been designed and constructed by the Naval Research Laboratories, Washington, D. C. It is stationed and used for a long-range research program at the Naval Medical Research Institute.

Description

(See Figures 4-1, 2, 3) A flywheel is connected to the vibration machine through a splined-type multiple friction-plate clutch which is magnetically operated and especially designed for this system.

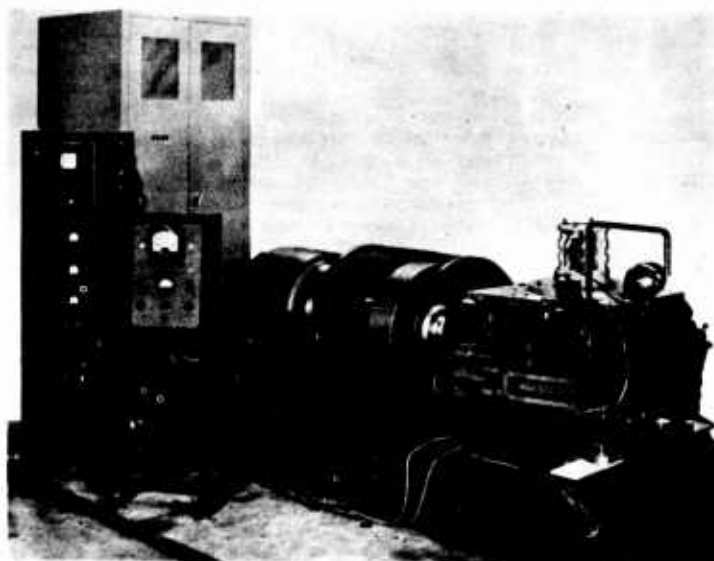


Figure 4-1. Naval Medical Research Institute, Large Displacement Amplitude Vibration machine: From left to right: Control system, drive, clutch, vibration table.

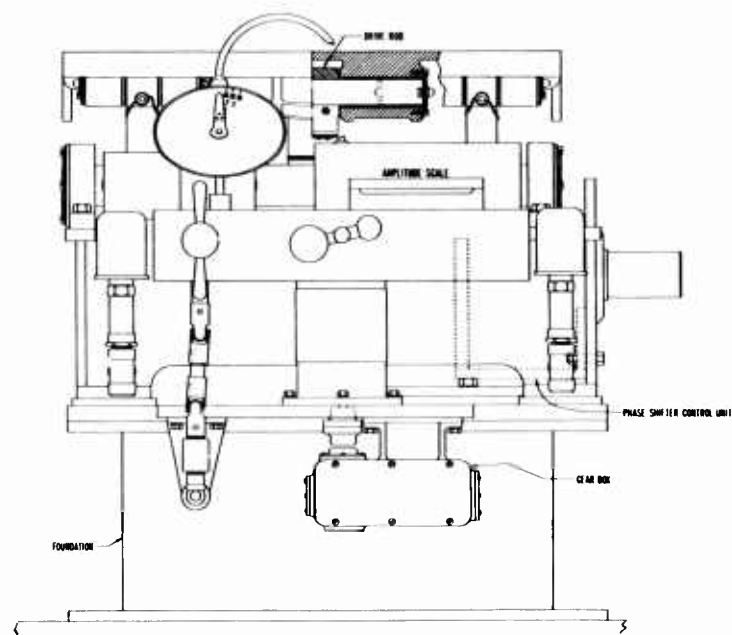


Figure 4-2. Naval Medical Research Institute,
Large Displacement Amplitude Vibration
machine: Vibration machine assembly,
front elevation.

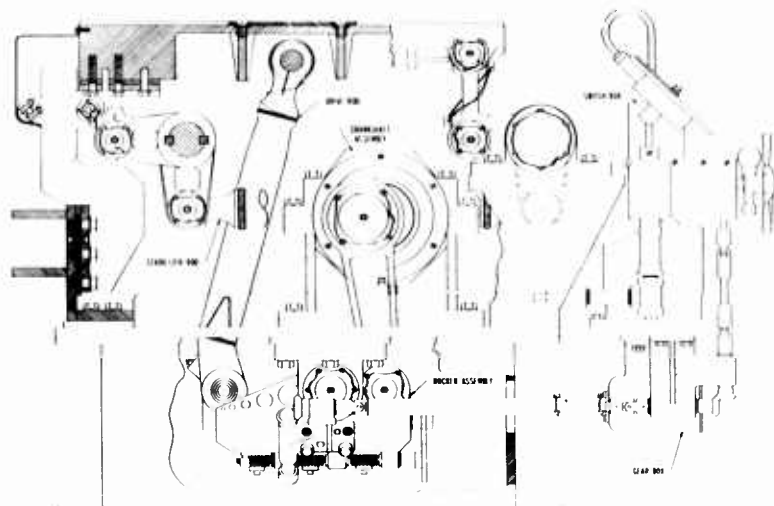


Figure 4-3. Naval Medical Research Institute,
Large Displacement Amplitude Vibration
machine: Vibration machine assembly,
side elevation.

During operation of the machine the main shaft drives a crank and a connecting rod which in turn actuates a rocker arm. A second connecting rod is dovetailed at one end into the rocker arm; it drives the vibration table at the other end. By means of a vertical guide post and a stabilizing linkage system, the table is constrained to move in a vertical direction. The dovetailed end of the connecting rod is actuated by a screw in the rocker arm so that its position on the arm is adjustable. By a suitable gear arrangement, the screw can be rotated from a control panel through a telescoping shaft which is also connected to the amplitude-control motor.

Motion Capabilities

The machine is designed for a maximum tableload rating of 200 lbs. at any combination of displacements and frequencies not exceeding a 15-g peak acceleration. The frequency range is 2.2 to 50 cps. The excursion or total travel is variable from zero to four inches and may be changed continuously while the machine is operating. The essentially harmonic motion of the table occurs only in the vertical direction.

A velocity and acceleration waveform obtained in the direction of table motion (vertical) is shown in Figure 4-1 for a 250-lb. tableload.

Control System

The large displacement-amplitude vibration machine operates on an open-loop system. The main operating control panel includes a push-button start-and-stop switch for the main drive motor, a potentiometer for speed control, and an indicating lamp which is energized when the motor is operating. Speed is indicated on a tachometer which receives its signal voltage from a generator driven by the main motor.

Safety Features

Dynamic braking of the flywheel occurs when the stop push button is operated. A push-button start-and-stop switch for the magnetic clutch is also included on the main control panel, together with an indicating lamp which is energized when the clutch is engaged.

Information

For information contact Commander D. Goldman, MSC, USN at Naval Medical Research Institute. For design information contact

Robert W. Conrad, Shock and Vibration Branch, Mechanics Division,
Naval Research Laboratory, Washington, D. C.

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1. Forkois, H. M. and Conrad, R. W., "A Large Displacement-Amplitude Vibration Machine for Physiological Applications," Report 4151, June 4, 1953.

5. BOEING HUMAN-VIBRATION FACILITY (Airplane Systems Laboratories, Wichita, Kansas)

Introduction

The Boeing Wichita Human-Vibration Facility was developed by Airplane Systems Laboratories to determine practical answers to design questions regarding human performance capability under low-frequency, high-amplitude vibration environment. It was designed so that a wide range of human performance tests and physiological measures for correlation or control purposes could be conducted with physical environment control.

Description

(See Figure 5-1) The 30 by 48-inch vibration table was designed so that various subject and equipment arrangements could be mounted on it. It is actuated by a double-acting hydraulic ram.

A standard aircraft pilot's seat is adjustable vertically to accommodate various body sizes. The aircraft simulation control column is an aircraft-type control wheel assembly with respect to dimensions and work-place location. Aircraft control forces can be simulated and varied to suit the testing condition. Linkages may be provided between the control column and the displays.

The vibration table is enclosed in an experimental room, so that the subject is isolated from all personnel, equipment, and undesirable environmental factors. The subject can be observed, without being distracted, through one-way vision windows (See Figure 5-2).

Motion Capabilities

At present the facility is capable of producing sinusoidal vibrations in the vertical plane of either constant amplitude or varying amplitude which may be controlled either automatically or manually. A vertical displacement of ± 5 inches is possible through a frequency range of zero to 30 cycles per second. Almost any equipment configuration up to 1,000 lbs. (including subject) can be readily mounted to the platform.



Figure 5-1. Boeing Human-Vibration Facility:
Seat and subject arrangement.

The facility has provisions for growth which includes: An amplitude of ± 10 inches, random amplitude and frequency as well as programmed inputs, automatic or manual frequency-rate control, and frequencies up to 60 cycles per second.

Control System

The experimenter controls the test procedure and conditions from an experiment-control station.

The operation of the vibration equipment and most recording of data is accomplished at a system-control station. These two stations and the vibration chamber are interconnected by a voice communication system. The actuation of the vibrating table is

controlled by a servo valve which receives electrical inputs from computer circuits. Two vibration cut-off switches are available at the control station for the experimenter and observer.

Safety Features

Voice communication between experimenter and subject, and between experimenter and equipment-control operator are provided. A portable cut-off switch can be carried to any part of the observation area.

Information

For information contact the Human Factors Unit, Engineering Department, Boeing Airplane Company, Wichita, Kansas.

Bibliography

Boeing Human-Vibration Facility, Boeing Report No. D3-3301, September 28, 1960.

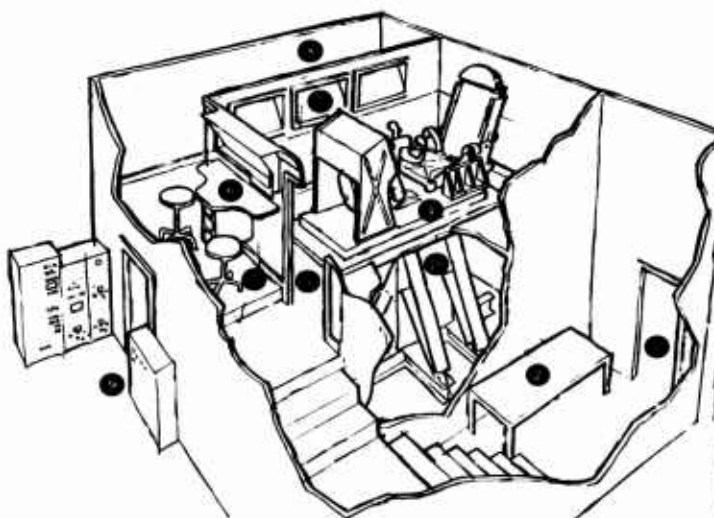


Figure 5-2. Boeing Human-Vibration Facility:
Layout of overall facility.

1. Entrance to lower level, 2. Subject preparation and interview room, 3. Subject's station, 4. Vibration platform, 5. Experimental control station, 6. Control panel and observation window, 7. (3) one-way viewing windows, 8. Observation area, 9. Equipment operator's station, 10. Hydraulic ram mechanism.

6. HIGH-AMPLITUDE VIBRATION MACHINE (Wright Air Development Division, Ohio)

Introduction

The high-amplitude vibration machine is a test instrument designed by the Western Gear Corporation for Wright-Patterson Air Force Base. It is used for studying human tolerance and biodynamic problems at high-vibration amplitudes and also for testing seats, harnesses, and other equipment.

Description

(See Figure 6-1) The mechanical system is of the brute force type. A special scotch yoke type mechanism is used to convert rotary motion into linear sinusoidal motion.

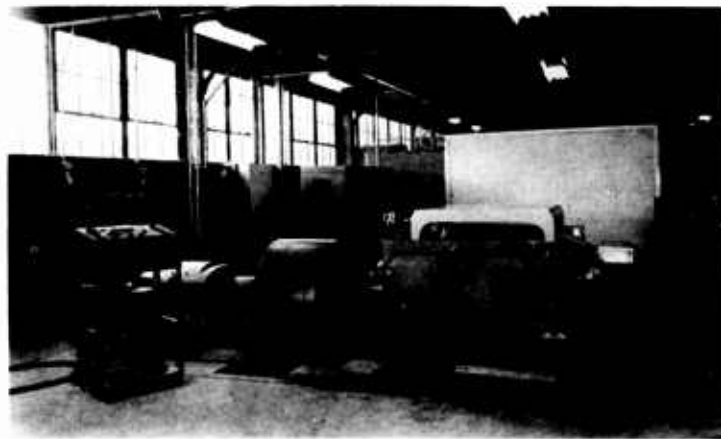


Figure 6-1. WADD High-Amplitude Vibration Machine.

Motion Capabilities

The machine is designed for sinusoidal motions in either a horizontal or vertical plane. The maximum load is 100 lbs. at four g's. With the test specimen loading reduced to 218 lbs., the machine is capable of operating at 0.4 inches double amplitude up to

30 cps. The frequency range is 2-30 cps. adjustable in 0.02-cps. increments. The table double amplitude is infinitely finely adjustable between 0 and 9 inches.

Control System

The control system used is a precision electric frequency-control system. Differential gearing in connection with adjustment motor allows the adjustment of table double amplitude while the machine is in motion.

Safety Features

A regenerative braking circuit is used for rapid stopping of the 50-hp. motor under normal or emergency conditions. An emergency band-type brake is provided for rapid stopping of the flywheel. A pilot light indicates when the machine is set at maximum amplitude.

Information

For information contact Dr. H. E. von Gierke, Chief, Bio-Acoustics Branch, Aerospace Medical Laboratory, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio.

Bibliography

Ziegenruecker, G. and Magid, E. B., "Short-time Human Tolerance to Sinusoidal Vibrations," WADD TR 59-391.

7. FIVE-DEGREE-OF-FREEDOM MOTION DEVICE (proposed)
(Aerospace Medical Lab., Wright-Patterson Air Force Base,
Ohio)

Introduction

The purpose of the facility will be to explore human tolerance and performance under high-level angular and linear oscillations as they are anticipated during the re-entry phase of space vehicles, low-altitude, high-speed flights of airplanes and operation of escape systems at high speed. Simultaneous operation (open and closed-loop) of all five degrees of motion with programmed acceleration patterns will be possible to simulate actual aerospace environments. Preliminary design and feasibility studies have been conducted by the Franklin Institute, Philadelphia, Pa., and by the Bio-Acoustics Branch, Aerospace Medical Laboratory, Wright-Patterson AFB, Ohio.

Description

The device will provide motion in five degrees of freedom by an electrically controlled hydraulic system. The test platform will be supported by hydraulic cylinders with a maximum amplitude of nine inches. Each cylinder will be connected to an electrohydraulic control valve and will have a transducer to measure the actual displacement. A function generator will give the input to the electrohydraulic valves which will be connected with the displacement meters to the feedback control loops. By changing the phase in the feedback-control loops it will be possible to produce any random linear and angular motion within the given frequency, amplitude, and acceleration limits.

Motion Capabilities

This device will have the capability of producing vertical linear motions from zero to 30 cps. with a nine-inch double amplitude and a maximum velocity of 95 inches/sec. The device will also be capable of producing linear horizontal motions in the 0-30-cps. range with a maximum displacement of five inches double amplitude and a maximum velocity of 75 inches/sec. The maximum load will be 1,000 pounds.

Vertical angular motions of up to ± 15 degrees pitch and roll and horizontal angular motions of ± 30 degrees yaw will also be possible.

Combinations of motions in all five degrees of freedom will be possible.

Control System

A detailed description of the control system is not available.

Safety Features

The five-degree-of-freedom motion device will have several safety features. Cut-off switches will be provided so that an experiment can be stopped by any one of three people; the medical monitor, the subject, or the operator of the machine. Constant voice communication will also be possible. Safety switches will be provided in the machine to automatically stop the machine in the event of hydraulic or power failure.

Information

For information contact the Bio-Acoustics Branch, Aerospace Medical Laboratory, Wright-Patterson AFB, Ohio.

8. PITCH-ROLL CHAIR (NASA Ames Research Center, Moffett Field, Calif.)

Introduction

The Pitch-Roll Chair was designed by the Ames Research Center of the National Aeronautics and Space Administration for the purpose of simulating motion patterns of re-entry vehicles and studying man's physiological performance when he is subjected to various conditions. The chair has also been used in studies of general performance and general longitudinal control-system and airframe dynamics.

Description

(The device is shown in Figure 8-1.) A detailed description is not available.

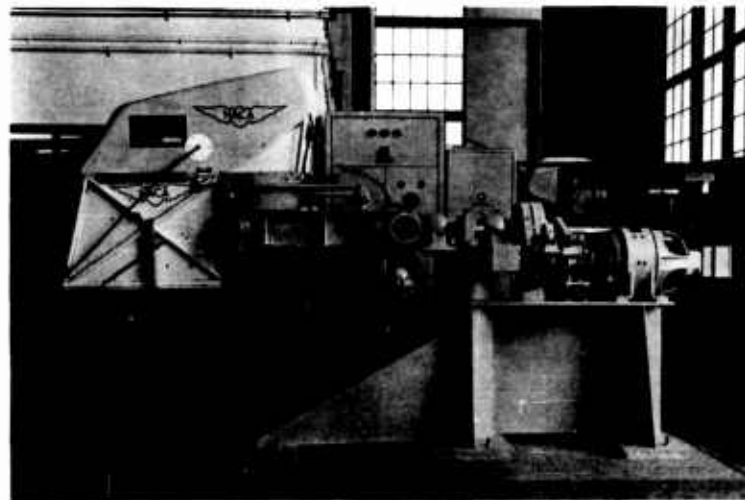


Figure 8-1. NASA Pitch-Roll Chair

Motion Capabilities

The chair is capable of rolling $\pm 1,080$ degrees (three revolutions), with an acceleration of 15 rad/sec.^2 and a velocity of eight rad/sec. About the pitch axis a displacement of -15 degrees to

+ 40 degrees, a velocity of two rad/sec., and an acceleration of 10 rad/sec.² are possible. The frequency response of the simulator is indicated by the following frequencies for 90-degree phase lag: roll four rad/sec. and pitch 15 rad/sec. In practice a lead term is used in the drive for the roll that results in 90-degree phase lag at 12 rad/sec.

Control System

The simulator is usually operated in a closed-loop manner with the pilot introducing control signals with a control stick and/or rudder pedals. These control signals are fed into a general-purpose analog computer in which the appropriate airplane control-system dynamics, airplane dynamics, and problem or task geometry are simulated. The roll-and-pitch angle signals from the computer drive the cockpit. Other signals defining the airplane's attitude or condition are presented to the pilot on instruments.

Safety Features

Emergency-stop switches are provided in the cockpit and various other locations. Also limit switches and overcurrent circuit breakers to limit angular displacements and acceleration are installed.

Information

For information contact Flight Research Branch, Ames Research Center, Moffett Field, California.

Bibliography

1. Creer, Brent Y., Stewart, John D., Merrick, Robert B., and Drinkwater, Fred J. III, "A Pilot Opinion Study of Lateral Control Requirements for Fighter-Type Aircraft," NASA Memorandum 1-29-59A.
2. Rathert, George A. Jr., Creer, Brant Y., and Doubillier, Joseph G. Jr., "The Use of Flight Simulators for Pilot-Control Problems," NASA Memorandum 3-6-59A.

9. PITCH-ROLL SIMULATOR (NASA Langley Research Center, Langley Field, Virginia)

Introduction

The Pitch-Roll Simulator has been designed and built by NASA Langley Research Center for the purpose of simulating various conditions encountered during re-entry and for studying man's performance under such conditions. It is also used to determine and examine problems of angular motion simulators.

Description

The device has been assembled in 1960. A detailed description is not available.

Motion Capabilities

The Pitch-Roll Simulator is capable of movements in the six normal degrees of freedom. The position and motion of the seat are determined by the solution of Euler axis transformation. The rolling and pitching motions may reach a maximum angular velocity of 60 degrees per second.

Control System

The device will be tied to an analog flight simulator and the pilot will close the loop.

Information

For information contact R. W. Stone, Jr., Aeronautical Research Engineer, Stability Research Division, Langley Field, Virginia.

10. GRUMMAN MOTION SIMULATOR (Grumman Aircraft Corp., Bethpage, N. Y.)

Introduction

The Grumman Motion Simulator was built by the Grumman Aircraft Engineering Corporation as a part of a multipurpose simulator laboratory designed to make available flexible equipment which can be breadboarded together to simulate various situations. The motion simulator or simulator platform was included in this equipment because it was felt that where the human is a critical element in the loop acceleration cues are needed for successful simulation.

Description

(See Figure 10-1) Mechanically, the system consists of two vertical rods which guide linear-motion ball bushings at points A and B of Figure 10-2. There is a horizontal sliding rod mounted in two other ball bushings; this allows the main axis AB to extend when the simulator is rolled. Point C is mounted on a rod which is allowed to pivot at its base. The three hydraulic servos consist of piston-type hydraulic motors rated at 17 horsepower. These may be operated up to 38 hp. intermittently, and drive the load through a 15-1-ratio helical gear-reduction and cable system. Three-turn potentiometers are geared to the top pulleys and are used for position feed-back.

Motion Capabilities

The simulator has three degrees of freedom; roll, pitch, and yaw, which can be operated simultaneously with complex motion patterns. It consists of three hydraulic servos which position the three points, A, B, and C, in a plane, as shown in Figure 10-2; this plane has approximately a six-foot vertical motion. Points A and B are moved differentially for roll, and point C for pitch. The pitch axis can be moved from the mechanical axis AB to infinity; the number of degrees of rotation then is limited by the vertical component. The simulator is capable of 1.6-rad/sec. angular velocity and 5.2-rad/sec.² angular acceleration through a displacement of ± 30 degrees about the roll axis. About the pitch axis, the device is capable of ± 15 degrees displacement, an angular velocity of 0.82 rad/sec.,

and an angular acceleration of 2.6 rad/sec.^2 . With a total load on the servos (all servos) of 1,000 lbs., the simulator is limited to three-g acceleration about the yaw axis for structural reasons and a six-foot displacement for mechanical reasons.



Figure 10-1. Grumman Motion Simulator:
Overall view.

Control System

This motion simulator is a fairly flexible machine. The dynamics of each problem will be handled on the analog computer, which will position the simulator. The simulator may be operated either closed or open-looped or a combination of both. The servos are positional and receive their commands from the computer. The simulator will follow the output of the computers as long as the commands do not exceed the response characteristics of the simulator.

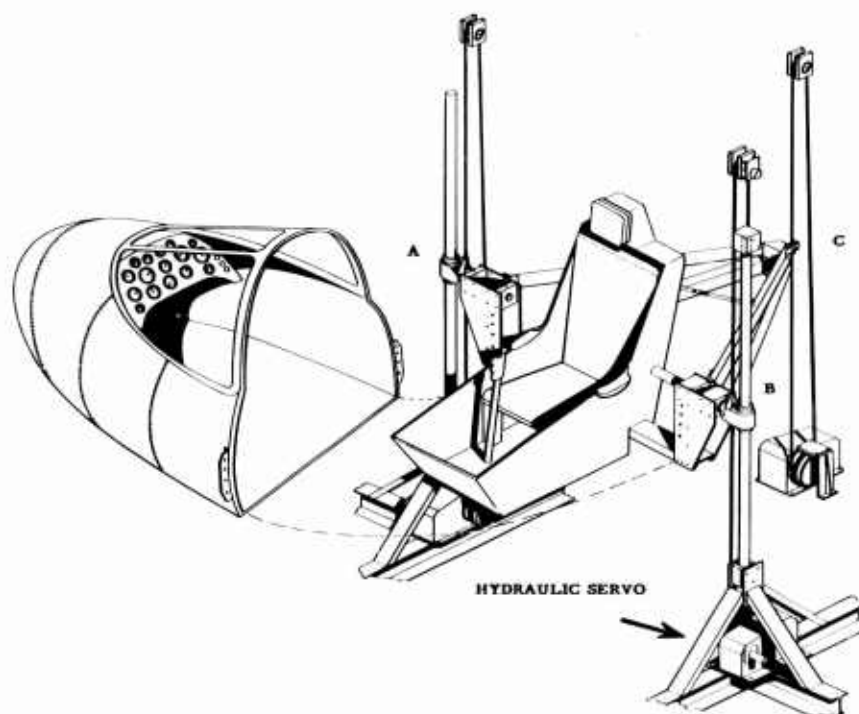


Figure 10-2. Grumman Motion Simulator:
Schematic.

Safety Features

Three limits are put on the maximum displacement of the simulator. The first is on the maximum values for which the computer can solve. If these limits fail, the second, consisting of switches limiting the displacement of the simulator, return the computer to rest, and the simulator to its neutral position. If the simulator should override these limits the hydraulic power is shut off by another set of switches. The pilot also has a "panic" button with which he can put the computer into reset. Seat straps are used to restrain the pilot (See Figure 10-2).

Information

For information contact E. J. Kennelly, Research Department, Grumman Aircraft Engineering Corporation, Bethpage, New York.

Bibliography

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2. Kennelly, E. J., Pesold, G. C., "Multi-Purpose Simulator Platform," Preliminary Research Report GAEC, August 1958.
3. Kennelly, E. J., "Development of a Multi-Purpose Research Simulator," Grumman Research Brochure, February 1959.

11. IRON CROSS (National Aeronautics and Space Administration)

Introduction

The Iron Cross was constructed by the National Aeronautics and Space Administration to conduct control studies of various reaction-control systems and not primarily as a motion simulator. However, it has certain capabilities for pilot motion studies.

Description

(See Figure 11-1) The device consists of two steel "I" beams welded together in the form of a cross which is mounted on a supporting strut by means of a free-swiveling joint at the center of gravity. The pilot's seat is located 13 feet ahead of the pivot point.

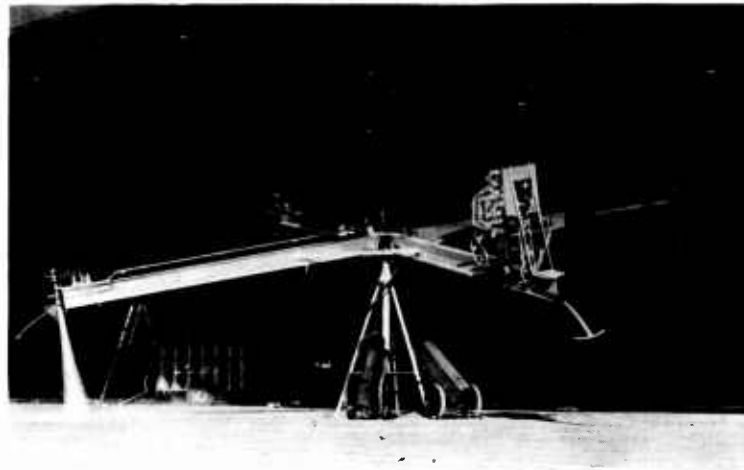


Figure 11-1. NASA Iron Cross.

Motion Capabilities

The device is free to rotate through ± 25 degrees roll, ± 20 degrees pitch and 360 degrees yaw. Movement is obtained from the forces produced by reaction controls such as the jet nozzles shown in Figure 11-1.

Since the moment of inertia and control torques can be varied, the maximum capabilities of the device will depend upon the control system being tested. Therefore, the following values are representative of typical systems, but are not necessarily maximum capabilities. The device is capable of an angular acceleration about the pitch, roll, and yaw axes of 10 degrees/sec.² and an angular velocity of 20 degrees/sec. about the same three axes.

Control System

The control system is actuated from pilot command through a three-axis side-located control stick. A closed-loop or open-loop control system is available about one axis and an open-loop system about the other two axes.

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12. THREE-DEGREE-OF-FREEDOM MOTION
SIMULATOR (proposed)
(Five-degree-of-motion centrifuge-proposed)
(NASA Ames Research Center, Moffett Field, Calif.)

Introduction

Ames Research Center has proposed a three-degree-of-freedom motion simulator for the purpose of studying man's performance when he encounters various flight problems. The control layout in the simulator cab will be a replica of the layout of whatever craft is being simulated.

It is planned that the cab, gimbals, and gimbal-drive system of the three-degree-of-freedom motion simulator will be mounted on a 30-foot arm which can be rotated in a horizontal plane. In addition it will be possible to translate the cab and gimbal combination vertically. Thus five degrees of combined angular and linear accelerations will be possible. The exact details of the centrifuge and vertical drive systems have not been finally decided.

Description

(See Figure 12-1) All three gimbals--roll, pitch, and yaw--are driven by d-c electric motors through "silence chain" power transmission. From motor to chain transmission is through a conventional sprocket. Final transmission of power to the gimbals is through friction between the chain and the rubber-surfaced gimbal-drive ring. This system has been determined to provide minimum lost motion.

Motion Capabilities

The flight simulator will be capable of rotating about the roll, pitch, and yaw axes. A maximum velocity of eight rad/sec. and a maximum acceleration of 18 rad/sec.² will be possible through a displacement of ± 360 degrees about the roll axis. About the pitch axis the simulator will be capable of displacing ± 45 degrees and will be capable of obtaining a maximum velocity and acceleration of two rad/sec. and six rad/sec.² respectively. The motion capabilities for rotation about the yaw axis are the same as those motion capabilities for rotation about the pitch axis.

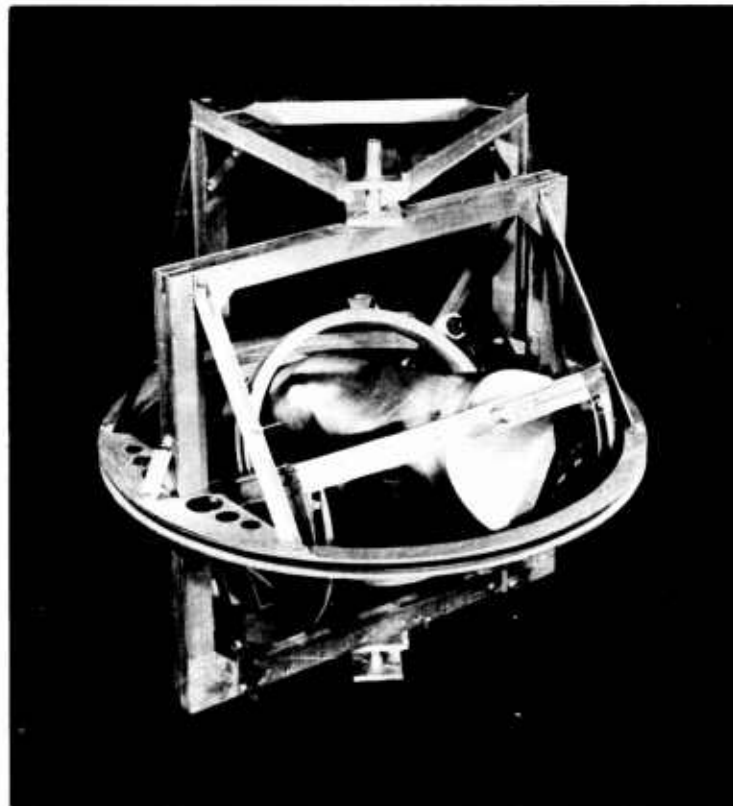


Figure 12-1. Model of the NASA three-degree-of-motion simulator (proposed).

The centrifugal acceleration on the centrifuge will reach a maximum of 6 g with a maximum angular velocity of 2.5 rad/sec. and a maximum angular acceleration of 2.5 rad/sec.². The maximum linear acceleration of the cab planned is two g with a maximum displacement of ± 7 ft.

Control System

The simulator will almost always be operated by a closed-loop system. Equations relating motion to controls will be the response equations of whatever vehicle is being simulated.

Safety Features

Acceleration limits are provided in the computer and in the drive system. Manual emergency-stop buttons are provided in the cab and on the computer.

Information

For information contact Flight Research Branch, NASA Ames Research Center, Moffett Field, California.

13. LANGLEY RESEARCH CENTER NAP SIMULATOR (Langley Research Center, Langley Field, Virginia)

Introduction

The National Aeronautics and Space Administration Flight Research Division has designed and built a simulator for the purpose of studying piloting problems associated with the longitudinal control of aircraft. The simulator is primarily suited for investigations requiring the pilot to track a programmed target by manipulating his control stick which then, through the simulated aircraft dynamics, moves his cockpit in the desired direction. These motions of the simulator subject the pilot's body to the proper forces to provide him with the "feeling" of actual flight for the conditions of tracking or close formation flying where altitude must be controlled within about eight feet.

Description

(See Figure 13-1) A control stick is mounted in the cockpit of the simulator and is connected to a spring in order to supply control-feel forces. Stick motions are transmitted electrically through a synchro-generator connected to the stick to a synchro-motor mounted outside of the cockpit which, in turn, drives an electro-mechanical spring-mass-dashpot system which represents the dynamics of the aircraft configuration being simulated. The damping and the spring restoring or destabilizing moments of this system can be varied electrically in order to cover a wide range of period and damping from that experienced by conventional aircraft flying at high speeds and low altitude to the long-period motions expected at extreme altitudes. The electro-mechanical simulator supplies the signals to control the pitch angle and normal acceleration of the simulator cockpit simultaneously.

Motion Capabilities

Motion of the simulator cockpit is limited to ± 4 degrees rotation in pitch due to angle-of-attack command and a usable vertical travel of eight feet. Normal acceleration response of the simulator along with a comparison to a jet fighter airplane is shown in Figure 13-2. In this comparison, no attempt was made to adjust the simulator dynamics exactly to those of the airplane; even so,

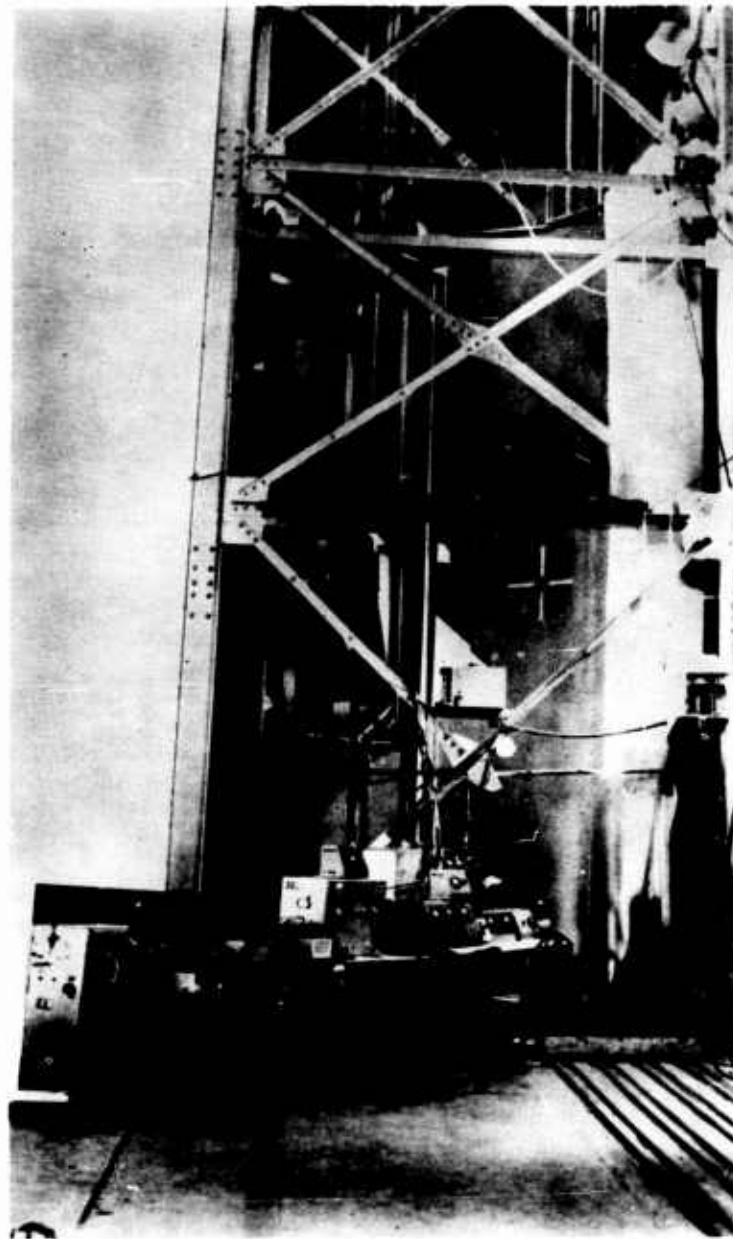


Figure 13-1. Overall view of the NASA Normal Acceleration and Pitch (NAP) Simulator.

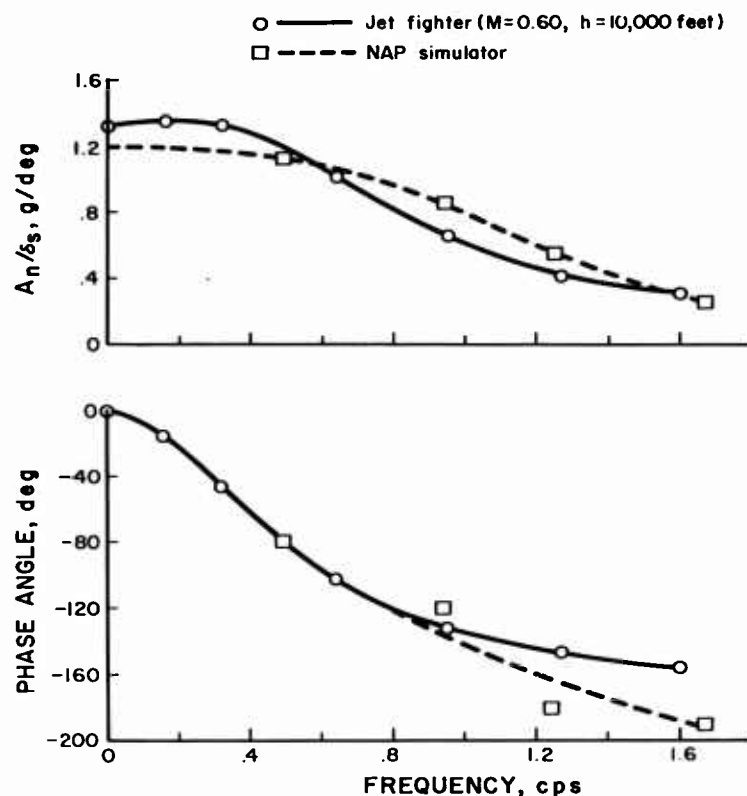


Figure 13-2. NASA NAP Simulator: Comparison of actual frequency response of a jet fighter airplane and the NAP Simulator.

the similarity in general trends are evident. It is apparent, however, that at frequencies above about one cycle per second the phase lag of the simulator increases rather rapidly compared to the airplane. These large phase lags at higher frequencies are attributed to power saturation of the first integrating servo in the vertical motion channel.

Control System

The simulator is operated as a closed-loop system, with the pilot participating in the loop by means of a control stick.

Safety Features

The static weight of the cockpit is counter-balanced with bungee cords that serve as a safety suspension system in the event of a failure of the main driving cable. An automatic cut-off system prevents the cockpit from being driven into the stops on the vertical rails in the event of a control circuit failure or pilot-induced oscillation. Provision is also made to limit the vertical velocity of the cockpit which is presently set at five feet per second so that in case the automatic cut-off is activated, the pilot will be subjected to an instantaneous peak acceleration of 4.5 g.

A duplicate control system is provided at the ground operator's control station so that in the event of a failure in the pilot's control system, the ground operator can assume complete control.

Information

For information contact Flight Research Division, NASA, Langley Research Center, Langley Field, Virginia.

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2. "Electric-Hydraulic Gun Drives for 5-inch 38-Caliber Dual Purpose Mount," Navy Ordnance Pamphlet 1103, 1945.

14. EQUILIBRIUM CHAIR

(Wright Air Development Division, Dayton, Ohio)

Introduction

The equilibrium chair was designed by the Aerospace Medical Laboratory, Wright Air Development Division, for the purpose of studying the effect of vibrations and buffeting on the vestibular organ and on simulated aircraft-control performance. The equilibrium chair is presently used on the high-amplitude vibration machine located at WADD, but will be used in the future on the vertical accelerometer. (Both linear vibration devices are described separately in this report.)

Description

(See Figure 14-1) The chair is driven by three hydraulic cylinders with electromagnetic control valves.

Motion Capabilities

The chair is capable of ± 20 degrees angular displacement about the pitch and roll axes. A maximum angular velocity of 40 degrees/sec. is possible. An acceleration or frequency response is not available.

Control System

The chair is actually "flown" by the subject. Random pitch and roll disturbances can be programmed for the chair.

Information

For information contact Dr. R. R. Coermann, Bio-Acoustics Branch, Aerospace Medical Laboratory, Wright Air Development Division, Wright-Patterson Air Force Base, Dayton, Ohio.

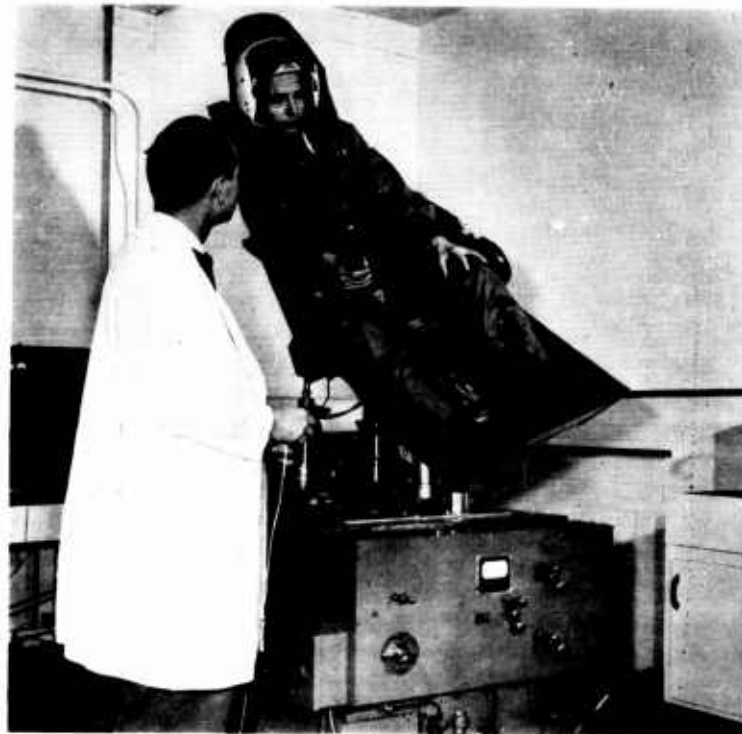


Figure 14-1. The WADD equilibrium chair mounted on a commercial linear vibration table. Extremes of range of motion are demonstrated.

15. RIDE-DYNAMICS SIMULATOR
(Hq. U. S. Army Ordnance Tank Automotive Command, Detroit,
Michigan)

Introduction

The ride-dynamics simulator has been designed and built by the U. S. Ordnance Tank Automotive Command and the Detroit Arsenal. The purpose of the device is to investigate the effects on human beings of motion induced by riding military vehicles. These investigations are being conducted by the U. S. Army Ordnance Tank Automotive Command in conjunction with the Willow Run Research Laboratories of the University of Michigan.

Description

(The device is shown in Figure 15-1) A detailed description is not available.

Motion Capabilities

The device has four degrees of freedom: yaw, pitch, roll, and bounce. About the yaw axis a maximum acceleration of 15 rad/sec.² is attained through a frequency range of 0-3 cps. and a displacement of ± 10 degrees. A maximum acceleration of 30 rad/sec.² through a frequency range of 0-10 cps. and an amplitude of ± 20 degrees is attained about the pitch axis. About the roll axis a displacement of ± 20 degrees and a frequency range of 0-10 cps. may be attained and an acceleration of 30 rad/sec.² may be produced. For bounce the motion capabilities are: acceleration two g, amplitude ± 1.5 feet, and a frequency range of 0-10 cps. Random motion can be programmed simultaneously for all four degrees of freedom. The input programming capability will be magnetic tape, analog computer, and digital computer through a digital analog converter.

Control System

The control system of the simulator is closed-loop.

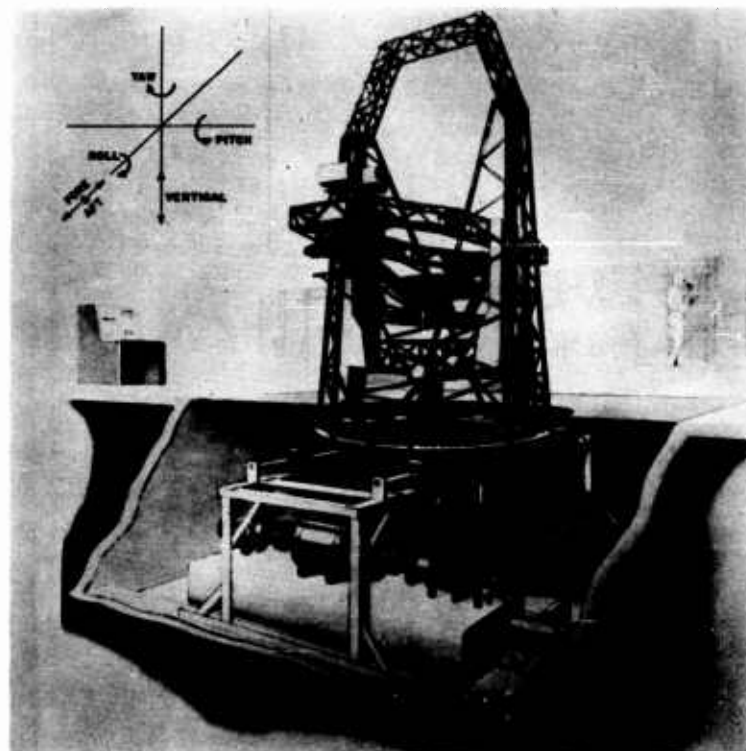


Figure 15-1. The Ride Dynamics Simulator
(U. S. Army Ordnance Tank Automotive
Command)

Safety Features

The simulator has hydraulic drives for all four degrees of freedom which are electrically controlled. A "deadman switch" will permit stopping of motion if necessary. Another safety device (details not available) will control maximum acceleration.

Information

For information contact Hq. U. S. Army Ordnance Tank Automotive Command, 1501 Beard Street, Mr. Savas Laskarides, Detroit 9, Michigan.

Bibliography

Letter descriptions from Hq. U. S. Army Ordnance Tank Automotive Command, 1501 Beard Street, Mr. Savas Laskarides, Detroit 9, Michigan.

16. BELL HELICOPTER FLIGHT SIMULATOR (Bell Laboratories, Fort Worth, Texas)

Introduction

The Bell Helicopter Flight Simulator was designed and built by the Franklin Institute, Philadelphia, Pennsylvania, in 1955 primarily for the human-engineering studies of problems resulting from short-term accelerations encountered in helicopter flight. The simulator attempts to make the pilot actually "feel" that he is flying the aircraft simulated.

Description

(See Figure 16-1) The simulator consists mainly of a dynamic platform upon which is mounted a helicopter cockpit.

The platform proper, a trussed frame about six feet square, is supported on the U-shaped roll gimbal by a pair of hydraulic cylinders, the blank ends of which are connected so as to form a hydraulic rocker. This allows the platform to rotate about the roll axis without requiring physical roll trunnions and bearings. Stability in the lateral and fore-and-aft directions is achieved by a pair of stub shafts in the platform hubs. These shafts are aligned on the pitch axis and are attached to the roll equilibrator piston rods at their outboard ends. The pitch actuator is located at the front of the platform and roll gimbal.

The roll gimbal is hung in the small yaw gimbal and stabilized by a pair of links connected by universal joints to a transverse yaw rocker in the rear. Rotation of this rocker, which forms a four-bar linkage with the links and roll gimbal, produces a yaw of the platform by means of a hydraulic cylinder.

The yaw gimbal is supported by two transverse trunnions from the curved "walking beam" which in turn is pivoted to a kingpost, the upper end of which carries the yaw rocker. The roll gimbal, walking beam, links and kingpost then form a second four-bar linkage capable of allowing motion of the platform in a vertical plane.

Transverse motion is produced by rotation of the kingpost about the vertical axis, while keeping the yaw rocker fixed in space

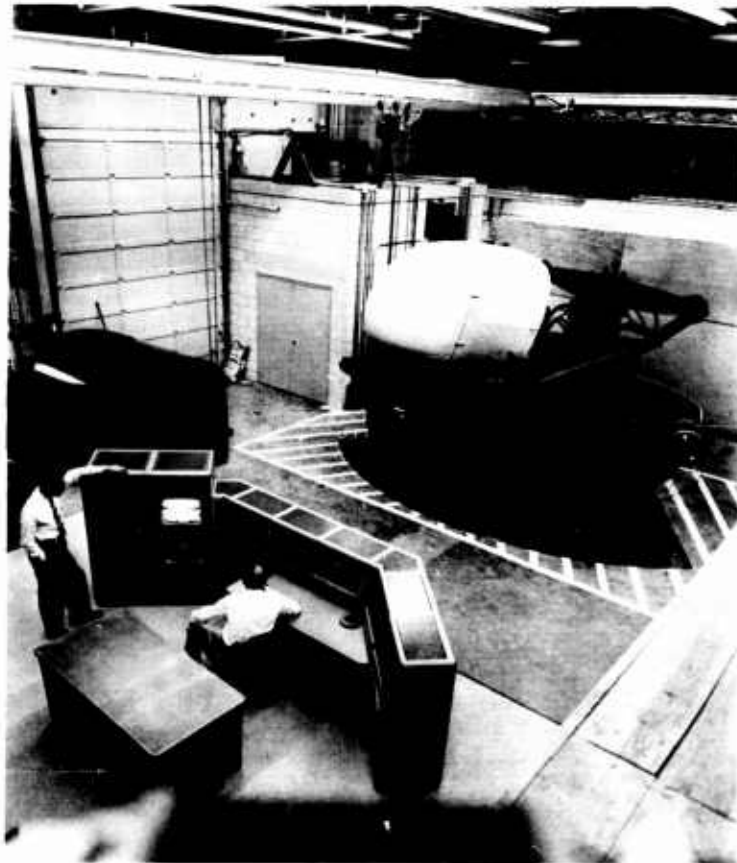


Figure 16-1. The Bell Helicopter Flight Simulator.

by proper compensation through the yaw cylinder. Rotation about an offset axis of the eccentric carrying the kingpost causes fore-and-aft displacement. The actuators producing these motions are attached to a pylon adjacent to the eccentric. Suitable links and bell cranks make it possible to compensate each motion for the effect of the other, so that pure linear displacements without rotation can be achieved.

The bearing housing of the eccentric is mounted on a foundation of heavy I-beams imbedded in a circular reinforced concrete foundation which forms the bottom of a seven-foot deep pit, 14 feet in diameter.

Motion Capabilities

The platform is capable of producing an acceleration of 40 degrees/sec.² through a displacement of ± 10 degrees about the roll axis; an acceleration of 25 degrees/sec.² through a displacement of \pm eight degrees about the pitch axis; and an acceleration of 15 degrees/sec.² through a displacement of ± 10 degrees about the yaw axis. It is capable of displacing vertically a distance of + eight feet, + seven feet laterally, and + 20 inches in fore-and-aft with an acceleration of 0.3 g. The maximum velocities are those corresponding to a sinusoidal acceleration maintained through the specified range.

Control System

A closed-loop system is used with the platform being manually controlled during the preliminary phase of an experiment.

Safety Features

The range of motion of all components is limited by the strokes of the hydraulic cylinders, which prevent physical interference between them in their extreme positions.

Since the servo control valve is the last link in the control chain, failure of this component, e. g., due to clogging by impurities in the hydraulic system, is the potentially most serious emergency condition. Protection against this is afforded by electronic limiters.

Since control of the decelerating forces is not sufficient to ensure that the platform will be arrested within the given range of overtravel, the velocity is limited by limiting the flow of oil through flow-control valves, in those channels in which such limitation is not provided by resistance of lines, valves, fittings, etc.

Information

For information contact Bell Helicopter Corporation, Fort Worth, Texas. The Franklin Institute Laboratories for Research and Development, Philadelphia 3, Pennsylvania, may be contacted for technical design information.

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17. "HEAVER" (proposed)
(Naval Air Development Center, Johnsville, Pa.)

Introduction

The "Heaver" is a proposed flight simulator based on a preliminary study by the Franklin Institute for the purpose of physiological performance studies, especially vestibular function studies. "Heaver" would have the capacity to oscillate the largest foreseeable protection devices and to carry complete cockpit mockups of various vehicles. The specifications of "Heaver" have been centered around the most acute problems which seem to be those of low flying aircraft at speeds up to 2,000 mph. This was done by extrapolating the data obtained during low altitude flight at speeds of 360 knots. Two versions of the "Heaver" have been considered in the feasibility study, which differ mainly in the means employed for producing vertical motion.

Version 1

Description

(See Figure 17-1) In the first version of "Heaver", vertical motion is produced by a pair of double-acting hydraulic cylinders whose piston rods extend through the bottom ends in order to equalize the forces produced in the upward and downward directions, and to keep the large flow required to a minimum. A 45-foot stroke is provided to allow a small amount of over-travel at either end.

The large flow of hydraulic fluid required presents one of the foreseeable difficulties of this scheme. Assuming a total carriage weight of 25,000 lbs., a 20-g acceleration would require a force of 500,000 lbs.

In order to avoid the necessity for large over-travel, it is desirable to limit the acceleration of the carriage at any point, so that, in the worst condition, the maximum deceleration occurs when the carriage is stopped at either end of its 40-ft. travel. This could be achieved by limiting the velocity of the carriage to correspond to the velocity it would have when subjected to a sinusoidally varying acceleration of maximum amplitude.

Motion Capabilities

The "Heaver" should be capable of vertically vibrating a 5,000-lb. payload at 20 g throughout a frequency range of one to 15 cps., and a lower acceleration at frequencies below one cps. The maximum vertical displacement should be 40 feet. A lateral displacement of $\pm 2-3$ feet at 2-3 g is desirable. The "Heaver" consists of a three-gimbal mount for the gondola; each gimbal rotating through 360 degrees at angular accelerations of up to ± 10 rad/sec.² and a maximum angular velocity of 10 rad/sec. Simulation of programmed complex or random acceleration patterns should be possible.

Control System

The "Heaver" will consist of cam, tape, or computer control with provisions for closed-loop control.

Safety Features

A detailed discussion of safety features has not been presented.

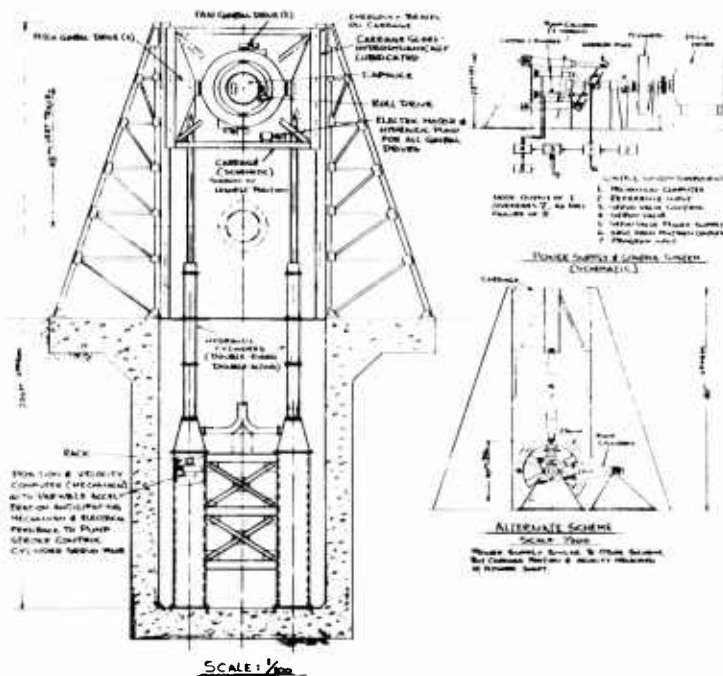


Figure 17-1. The "Heaver" Flight Simulator (proposed). The two versions considered in the design study are illustrated.

Version 2

Description

This version differs in the means employed for producing vertical motion. The carriage is elevated by means of a slider crank mechanism, with the carriage equivalent to the slider, and the long pistons replaced by a connecting rod about 60 feet long, which is attached to a light crank of 40 feet pitch diameter. The wheel is driven through a crankshaft and a suitable number of hydraulic cylinders. The pump is similar to the one used in the first version, but is located very close to the output cylinders, so that the length of lines, and thus the total volume of oil, can be greatly reduced. The effect on raising the natural frequency of the system would have to be determined, but it would very likely be higher than in the first version.

Motion Capabilities

The motion capabilities of version 2 of "Heaver" are the same as those presented earlier for version 1 of "Heaver".

Control System

The control system used in version 2 is identical to that used in version 1.

Information

For information contact Aviation Medical Acceleration Laboratory, U. S. Naval Air Development Center, Johnsville, Pa.

Bibliography

1. Aviation Medical Acceleration Laboratory, "Four Proposed Motion Simulators," U. S. Naval Air Development Center, June 17, 1958.

18. SHAKE TABLE FOR USE ON THE WADD CENTRIFUGE (Wright Air Development Division)

Introduction

A dynamic vibration table for use on the centrifuge has been designed, fabricated, and utilized successfully at WADD in support of chimpanzee performance tests (Project Mercury). The device provides the capability for producing a dynamic vibration environment in conjunction with the static "G" of the Aerospace Medical Division centrifuge. The combined system is capable of simulating the static and dynamic acceleration environment associated with the launch of ballistic or space vehicles.

Description

(See Figure 18-1) The shake table is a spring-mass system driven by an unbalanced force. The table mass consists of a large steel cylinder mounted between two rectangular aluminum plates. The two plates are attached to the steel cylinder so that they are perpendicular to the axis of the cylinder.

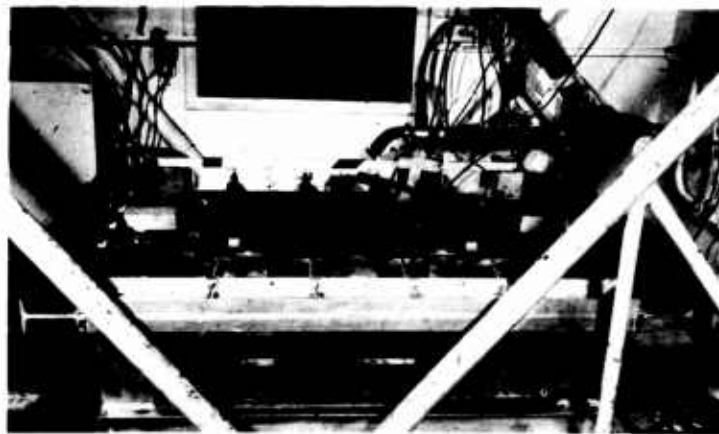


Figure 18-1. Shake table mounted on WADD centrifuge cab.

Two crank-shaft housings, one each at the top and bottom of the large cylinder, stabilize a crank shaft by means of bearings which allow the crank shaft to rotate freely within the cylinder. Attached to the crank shaft, at a point where a piston is normally attached, is a mass or weight. (Four interchangeable masses have been fabricated to vary the accelerating force.) As the crank shaft rotates, an unbalanced condition arises due to the added mass; that is, the axis of rotation is no longer the axis of the crank shaft, but an axis located between the crank-shaft axis and the added mass. Because of this condition the point on each of the two plates which lies on the axis of the crank shaft also moves about this new axis of rotation; thus, the plates vibrate.

The entire system table mass described above is surrounded by an aluminum frame. At the bottom of the frame is attached a bearing plate, containing three large bearing surfaces. Upon these surfaces lie three large bearings, which are attached to the bottom aluminum plate. These bearings allow freedom of movement of the vibrating assembly with respect to the frame. Extending between the top aluminum plate and the top of the frame are sixteen springs, four attached to each edge of the plate. The purpose of these springs is to control the motion of the vibrating mechanism, and also to serve as buffers.

The crank shaft is driven by a two-hp. D.C. electric motor by means of a flexible drive shaft. The flexible drive shaft is used since the motor is not mounted on the shake table, but at a distance approximately six feet from the table to prevent vibration of the motor. The total weight of the shake table is approximately 300 lbs.

Motion Capabilities

The shake table is capable of vibrating in the plane of the table with a circular motion through a linear displacement (amplitude) of ± 0.5 inches. The frequency range is 5.5 to 12 cps. This frequency range is limited by the resonance frequency of the springs attached to the system. The maximum acceleration which can be produced is a function of the weight attached to the crank shaft and vibration is dependent upon the static-g changes at right angles to the plane of the table.

Control System

The shake table operates by means of an open-loop system.

Safety Features

The springs limit the frequency of vibration. Buffers are also attached to the frame to limit the amplitude.

Information

For information contact Dr. H. E. von Gierke, Chief, Bio-Acoustics Branch, Aerospace Medical Laboratory, Wright Air Development Division, Wright-Patterson Air Force Base, Dayton, Ohio.

Bibliography

No report is available at this time.

19. NAVAL HUMAN CENTRIFUGE (Modification) (Naval Air Development Center, Johnsville, Pa.)

Introduction

The Naval Air Development Center has proposed a modification of its human centrifuge used by the Aviation Medical Acceleration Laboratory.

Ideally, the research vehicles which are to be simulated on this dynamic flight simulator should impose the limitations of angular acceleration and rates of change of acceleration, not the centrifuge capability itself. It has been cited that it was impossible to simulate some of the high-frequency oscillations in the X-15 program because of the low-frequency response of the control system of the existing centrifuge. Also, the simulation of such acceleration patterns as those produced by an uncontrolled aircraft and a catapulted or arrested aircraft requires high-frequency response characteristics of both the centrifuge and gimbal control systems.

For validity and reality of simulation, complete flight systems should be included. The pilot should be confronted with the entire task of the mission. He should be exposed to stress situations up to levels greater than those to be expected in actual flight conditions. In addition to the continuing problem of piloting the aircraft there should be simulation of combat encounters, navigation problems, and fire-control system decisions.

In connection with this report, the following items of the modification program are of interest: continuous rotation and oscillation capability of three gimbals (pitch, roll, and yaw); a 10-foot diameter spherical capsule; a special capsule with a linear vibrator; and improvements to the control system.

Description

(See Figure 19-1) A new and larger wing section on the centrifuge arm is required to support the interchangeable capsule. It is also desirable for certain studies to be able to attach this wing section with the controllable gimbals at a reduced radius. This reduced radius will lower the moment of inertia of the centrifuge

sufficiently to enable it to produce higher tangential accelerations and higher rates of change of centrifugal accelerations. The higher tangential acceleration capability will enable the centrifuge to simulate such G patterns as those associated with catapulting and arresting.

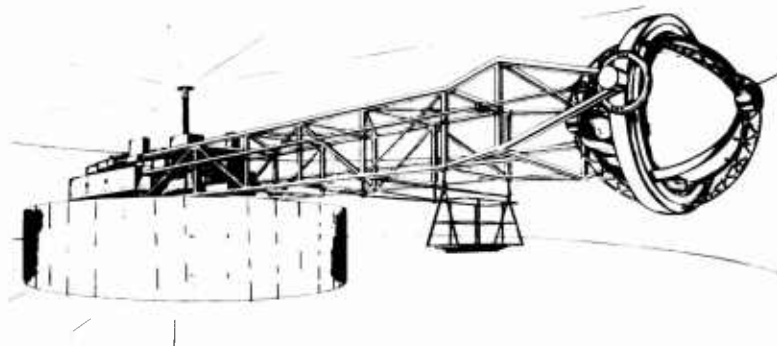


Figure 19-1. The Naval Human Centrifuge:
Modified centrifuge with new arm, wing
sections, three-gimbal system and twelve-
foot spherical capsule (artist's conception).

These requirements necessitate either a major modification of the present centrifuge arm in order to accommodate the new wing section at the two stations or a new centrifuge arm. Since the centrifuge arm is the basic structure upon which all modifications will be added, it is essential that it be sufficiently strong to safely withstand the extreme limits of stress which are available from the 16, 000-hp. DC motor which drives it.

A new gimbal system will be developed with continuous rotation in at least two degrees of freedom, pitch, and roll. Provisions will also be included for a possible third degree of freedom, yaw.

Four basic types of units are presently envisioned: A standard capsule, which contains no special provisions; a wall-temperature controlled capsule; a linear-vibration platform capsule, and a low-pressure altitude capsule.

These capsules will be larger than the present 10- by-six-ft. oblate spheroid gondola. Two cockpit configurations, placed side by side or in tandem, should be capable of easy accommodation, including fully instrumented panels, control consoles, ejection seats, etc. It is felt that a 12-ft. sphere will adequately serve the need for space.

Figure 19-1 is an artist's conception of how the modified centrifuge will look with a new arm, wing sections, three gimbals, and a 12-ft. spherical capsule.

Motion Capabilities

The centrifuge arm shall be designed to carry the standard capsule, gimbals, and 2,000-lb. payload to 20 g with full performance of the gimbals and centrifuge. 1,000-lb. payloads will be carried to 40 g with reduced system performance if necessary. An angular acceleration to exceed 10 rad/sec.² and an angular velocity of 30-rpm. maximum shall be possible for continuous rotation about any gimbal axis. Frequency response shall be constant within three db. from zero to approximately two cycles per second at an amplitude of ± 10 degrees rotation. Operation up to 40 g without appreciable changes in performance shall also be possible.

The linear-vibration platform shall be capable of four feet total displacement. It shall exert up to five-g acceleration and operate up to ten cycles per second. The system shall be capable of handling a rated payload of 1,000 lbs. in addition to the platform and shaker mechanism. The vibrating system shall be capable of operation in any axis while the centrifuge is operating up to 20 g.

Control System

Due to the rapid interchangeability of the capsules the control system will be such that the operator will be able to change from one mode of control to another by means of a patch panel. These various operating modes will include manual cam, tape, local generator, closed loop with a local or remote analog computer, and check operation.

Safety Features

Safety features shall be incorporated for the protection of subjects and operating personnel, such as an adjustable gimbal-angle limiting device, and a reliable communication system between subject and experimenters.

Information

For information contact Aviation Medical Accelerations Laboratory, U. S. Naval Air Development Center, Johnsville, Pa.

Bibliography

Crosbie, Richard J., "The Requirements for Modification of the Human Centrifuge for High Performance Aircraft and Space Vehicles Simulation Research," NADC-MA-5907, 6 July 1959.

20. DYNAMIC ESCAPE SIMULATOR (Under construction)
(Aerospace Medical Laboratory, Wright Air Development Division,
Wright-Patterson AFB, Ohio)

Introduction

This device is designed and built by the Franklin Institute, Philadelphia, Pennsylvania, and is expected to be operational before the end of 1961. Its design criteria are obtained primarily from escape accelerations. That is, by being capable of producing the sequential series of accelerations which characterize high-speed escape, this device necessarily is able to function as:

- (1) A medium-high performance general-purpose centrifuge.
- (2) A high-performance "disorientation device" for vestibular function studies. (This with the centrifuge arm standing still.)

Description

The device (See Figure 20-1) is a double-gimbaled centrifuge whose general configuration is that of a fork rotating about a horizontal axis at right angles to the main-axis drive. The fork-ends define the second gimbal (cab) axis of rotation.

The total power requirements are slightly less than 2,000 hp. The main drive mechanism is divisible into two functions: (a) acceleration drive and (b) sustaining drive. The accelerating drive utilizes small, high-speed flywheels engaged by air-operated friction clutches.

The sustaining drive utilizes approximately 600 horsepower-rated electric motors (continuous duty) driven by a separate motor generator set controlled by a Ward-Leonard system. A shake table is mounted in the cab.

Motion Capabilities

About the main axis a 20-g maximum centripetal acceleration is possible. The maximum rate of onset is 10-12 g/sec. with 2 g/sec. sustained.

An angular acceleration of 5-10 radians/sec.² (150 rpm) which varies with imbalance of cab payload is possible about the cab axis.

An acceleration of 20 radians/sec.² (30 rpm) may be produced about the fork axis.

A total payload of 1,000 lbs. is permissible with full gimbal performance at 10 g centripetal accelerations and 500 lbs. total payload with full gimbal performance at 20 g centripetal accelerations.

The cabs are spherical with inside diameter equal to six feet six inches. One cab may be pressurized to ± 12 psi.

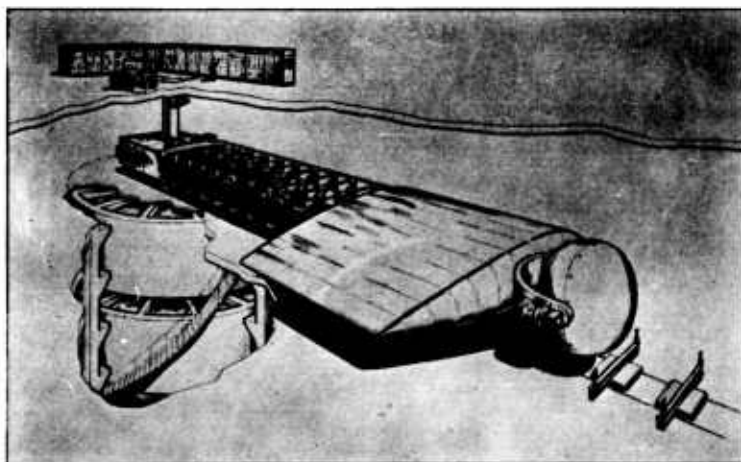


Figure 20-1. Artist's conception of WADD's Dynamic Escape Simulator (Under construction)

Motion Capabilities of Shake Table in Cab

The frequency range of the shake table is 1-15 cps. (low frequencies amplitude-limited at nine-inch single amplitude; higher frequencies g-limited at 15 g). The shake table payload is 500 lbs.

Bibliography

Centrifuge feasibility studies conducted during preliminary investigations regarding this new device are:

1. "Feasibility Study for an Advanced Device for Studying the Effects of Acceleration on Man," AF WADD-TR-59, July 1959.
2. "Feasibility and Design Study for an Advanced Human Environmental Research Accelerator," WADD-TR-60-225, March 1960.

These reports are listed for this general description only. The final Dynamic Escape Simulator Design deviates radically from these preliminary investigations.

21. "OMNIFLYER" (proposed)
(Naval Air Development Center, Johnsville, Pa.)

Introduction

The "omniflyer" is a six-degree-of-freedom motion simulator preliminarily designed by the Franklin Institute. Each of the three versions of "omniflyer" now being proposed has the capability of producing tremendous angular or linear impact or a combination of both. The motion capabilities and characteristics will be considered separately.

Version 1

Description

The mechanical system in Figure 21-1 illustrates a scheme wherein the gondola and gimbal system, enclosed in a supporting cage, are moved about an approximately cubical volume of space with cables. The cube in which the gondola can move is approximately 200 feet on each edge and is smaller than the structural cube illustrated in the drawing. The cables in the illustration are folded on a block-and-tackle arrangement to allow a comparatively short hydraulic cylinder to control the length of the cable. Assuming that the gondola is to be brought as near the wall of the cubical space as possible between four adjacent points at which the cables enter the cube, it can be seen that as the gondola approaches the wall the four supporting cables begin to pull, not towards the wall but away from each other and have a tendency to stress the structure of the gondola cage. This seems a somewhat dangerous situation. All cables which are not pulling the gondola must be pulled by the acting cables and might comprise an intolerable burden. It may be necessary to use tapered cables to support the loads. The building required for housing this version of "omniflyer" would be at least 300 feet square and about 250 feet high.

Version 2

Description

Version 2 is very similar to version 1. In version 2 of "omniflyer" the gondola and its gimbal system are moved by (a) two

hydraulic cylinders along the x-axis, (b) six hydraulic cylinders along the y-axis and (c) nine hydraulic cylinders along the z-axis. These three degrees of linear freedom allow motion anywhere within a cube 200 feet on each edge, and this motion can be at the same speed at almost any point within the confines of the 200-foot cube. The possibility of simulation of motion of a vehicle with this version of "omniflyer" seems greater than with any other version. As illustrated in Figure 21-2, a building enclosing version 2 shall be similar to the building enclosing version 1, but somewhat larger, approximately 650 feet by 800 feet on the base and 500 feet high.

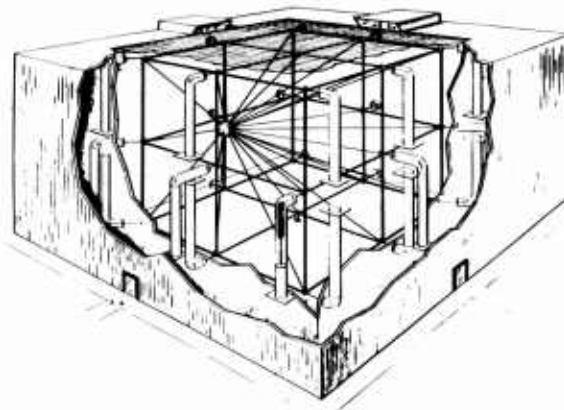


Figure 21-1. The NADC "Omniflyer" (proposed):
Version 1

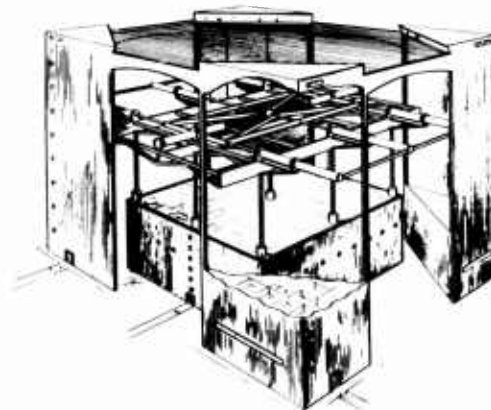


Figure 21-2. The NADC "Omniflyer" (proposed):
Version 2

Version 3

Description

Figure 21-3 illustrates a version of "omniflyer" in which there are five degrees of angular freedom and one degree of linear freedom. In addition to the three degrees of angular freedom of the gondola, the gondola-gimbal system is positioned anywhere within a 180-foot radius sphere by rotating the gondola support structure in both vertical and horizontal planes and simultaneously moving the gondola-gimbal system towards or away from the intersection point of these two axes of rotation. One hundred and eighty feet is about one-half the length of a corner-to-corner diagonal of a cube 200 feet on an edge. This illustrates that a rotating arm must be very much longer than the moving structure designed to meet motion specifications based on a concept of a cubical volume of space. A spherical space seems a little better related to the curvilinear motion of flying vehicles than does a cubical space. However, if the gondola is to pass rapidly near the axis of rotation, the angular velocity of the structure must be very high. This means that tip speeds of the rotating structure would be very great and the limit of speed of the gondola near the axis of rotation would be the strength of the rotating gondola support structure.

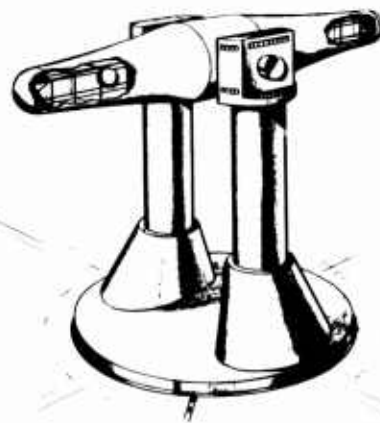


Figure 21-3. The NADC "Omniflyer" (proposed):
Version 3

The broad base of "omniflyer" in Figure 21-3 is for the purpose of support against overturning moments due to wind, unbalanced loads, and gyroscopic effects. This broad base could be

used as a horizontal centrifuge carrying tremendous payloads and it would be expected that several experiments could be set up simultaneously on this version of "omniflyer."

Motion Capabilities

(For all versions) All versions of "omniflyer" should be capable of maintaining the gondola at 50 g for radii between 50 and 100 feet during circular rotation as an aid in permitting freedom of choice as to the direction of motion. It should be capable of attaining levels of up to 50 g in a fraction of a second to simulate rocket-boasted vehicles. Since in its various versions it can move a subject vertically through distances between 200 and 360 feet it can permit two or three seconds of zero G. To meet the requirements of 50 g at a 50-foot radius the dual rotation version of "omniflyer" must attain a tip acceleration of 180 g. This, then, is the maximum level of impact which could be attained on "omniflyer." The gondola of "omniflyer" should have a maximum angular acceleration on the order of 20 rad/sec.² in all three gimbals at 50 g. The payload should be about 15,000 lbs. The gondola is shown in Figure 21-4.

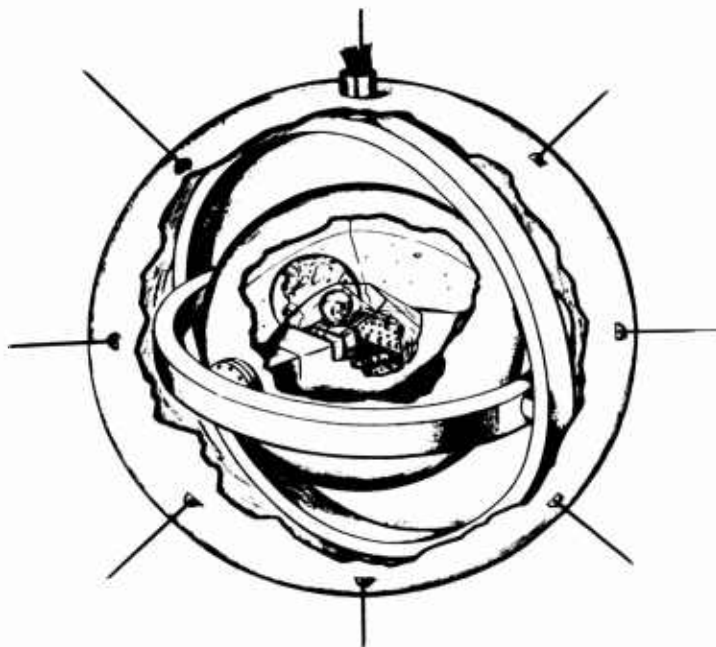


Figure 21-4. The NADC "Omniflyer" (proposed):
Capsule

Control System

Information pertaining to control is not available at the present time.

Safety Features

Information pertaining to safety is not available at the present time.

Information

For information contact Aviation Medical Acceleration Laboratory, U. S. Naval Air Development Center, Johnsville, Pa.

Bibliography

1. Aviation Medical Acceleration Laboratory report entitled: "Four Proposed Motion Simulators, " U. S. Naval Air Development Center, 1958.

22. WYLE OMNI-ENVIRONMENTAL SIMULATOR (Wyle Laboratories, El Segundo, California)

Introduction

The Wyle Omni-Environmental Simulator, built by Wyle Laboratories, provides a unique capability for reproduction of the environments which occur in various combinations during rocket-launch acceleration, deceleration, and re-entry. By providing simultaneously most of those environments which occur simultaneously, and at the same time permitting full performance of the test specimen, the Wyle system is particularly suitable for pre-flight testing of the space canary simian, its life support system and its internally implanted multi-channel biological telemetry system.

The simulator is equally useful for testing every kind of airborne system whose functional operation may be disturbed by elements of vibration, acceleration, altitude, temperature, and noise. Although size and weight limitations of the simulator are unknown, it is apparently designed to accommodate small animals only.

Description

(See Figure 22-1) The simulator consists essentially of an 18-foot diameter arm, with suitable structural ties, mounted on a hollow shaft through tapered roller bearings. Unique means are provided for installation of an MB C-25H or equivalent shaker, plus associated slip rings, swivels, tanks, plumbing, etc. The arm is designed to be easily removed from the hub assembly to permit preservation of a test set-up or the installation of a set-up on an alternate arm while a test is in progress.

The simulator is also equipped with altitude-temperature-humidity chambers and numerous electrodynamic vibrations systems with different payload capabilities.

Motion Capabilities

The simulator is capable of producing an acceleration of 20 g through continuous rotation about a vertical axis. The MB C-25H electro-dynamic vibrating mechanism mounted on the end of the arm is capable of producing a vibration force of 4,000 lbs. at a maximum

frequency of 2,000 cps. The frequency output will vary according to the type and size of vibration mechanism used. The Hydrashaker vibration system will produce a vibration force of 54,000 lbs. The maximum frequency of this system is not known for certain. One centrifuge attachment is capable of producing a 100-g acceleration on payloads less than 3,000 lbs., with modifications for producing 200-g accelerations.

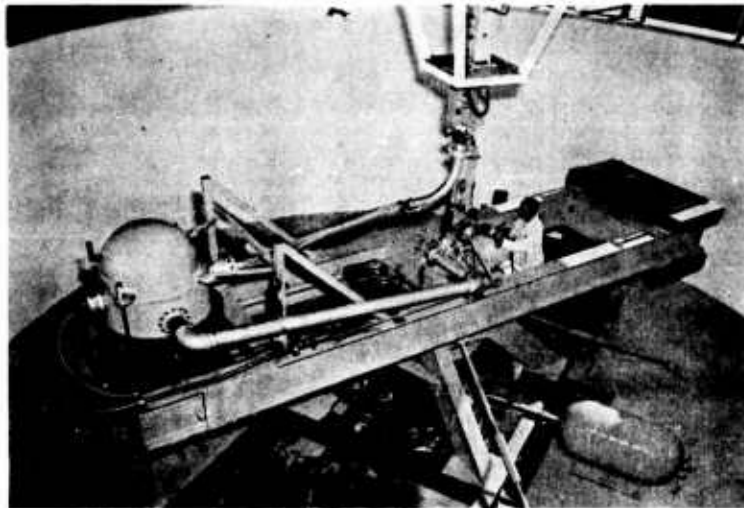


Figure 22-1. The Wyle Omni-Environmental Simulator.

The altitude-temperature-humidity chambers are also capable of simulating altitudes up to 250,000 feet, producing a temperature ranging from -300 degrees (F.) to 500 degrees (F.) and a humidity ranging from 50 to 95 per cent.

Control System

Details pertaining to the control system and safety mechanism are not available.

Information

For information contact Wyle Laboratories, El Segundo, California.

23. CIRCULAR TRACK-CHAMBER (Proposed) (Holloman Air Force Base, New Mexico)

Introduction

The laboratory testing of complex space flight missions today is not realistic because of the inadequacies of existing facilities. The multiple-stage boost at launch, for example, exceeds the capability of any conventional centrifuge as well as any long test track. To test the different space-flight phases such as launch, orbit, re-entry, and recovery, necessitates shifting the subject and hardware from one test facility to another.

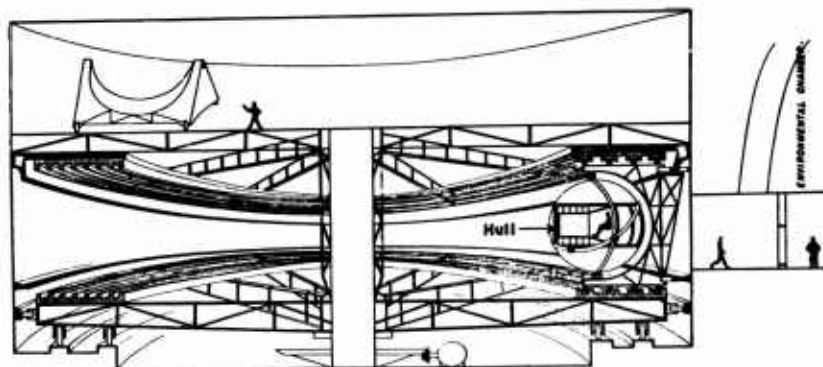
The purpose of the circular track-chamber is to test the capability of man-machine systems. The anticipated test procedure encompasses the simultaneous and continuous testing of most of the parameters of a complete space-flight history from launch through planet life to re-entry and recovery.

It can be used to evaluate the calculated mission profile for human tolerance and it will provide the means for the biotechnological evaluation of man-machine units to insure that the equipment will support the subject when exposed to the actual space environment. Other advantages accrue from the facility's usefulness in the selection and training of space crews and in the investigation of man's tolerance to unusual environment. The device has been planned by Air Force Missile Development Center, Holloman AFB, New Mexico.

Description

(See Figures 23-1 to 23-3) The circular track-chamber as proposed, combines a 100-foot-diameter circular track and a 100-foot-diameter hemispherical vacuum chamber into one composite test facility. Only the circular track chamber will be considered in detail.

The facility will handle payload-load factor products up to 2,000,000 pounds. To cover this wide range, two or three multipurpose sleds are anticipated.



CIRCULAR TRACK

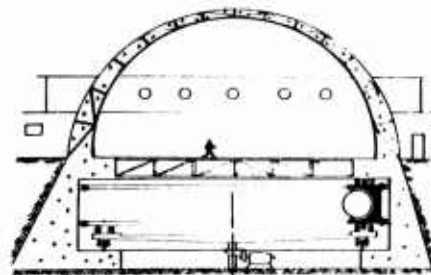
Figure 23-1. Proposed Circular Track Chamber (Holloman Air Force Base): Design concept.

The support of the test unit by a sled offers sufficient flexibility to accommodate all equipment needed to apply the required test parameters such as oscillation, noise, etc., as well as telemetering systems. The design concept of the circular track is shown in Figure 23-1. The heavy sled test unit is supported by an upper and lower set of rails. The lower set of rails is mounted on a continuously rotating flywheel. The latter can be coupled to the sled by brake shoes to drive the sled by its moment of inertia. The upper set of rails is stationary mounted to the wall. The arresting of the sled is governed by a second set of brakes (wall brakes). It is required that activation of the brake system is not bound time-wise to the relative position of sled and flywheel or sled and wall, but can be initiated, one brake system at a time, at any desired instant. Any acceleration profile is obtained by alternate application of the disc brake or the wall brake.

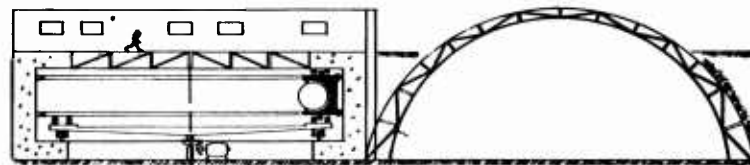
The requirement for pressure variation needs special consideration. The atmospheric pressure inside the space vehicle being tested is automatically controlled by the subject-system set-up as long as there is no leak. In case of a leak, the pressure outside of the space vehicle determines the pressure conditions inside. The test arrangement thus must provide an outside atmosphere for the test unit which can be varied according to the flight history. This can be accomplished by a hull structure surrounding the space vehicle (See Figure 23-1). The volume between space vehicle and hull provides for the anticipated outside atmosphere which can be controlled by two valves for pressure increase and decrease respectively. One valve connects hull volume with a high pressure bottle mounted on the sled. The second valve connects the hull volume with the track chamber which is evacuated. However, the most



OPEN PIT CIRCULAR TRACK



TWO STORY ARRANGEMENT



SIDE BY SIDE ARRANGEMENT

Figure 23-2. Proposed circular track - environmental chamber facility (Holloman AFB): An open pit circular track is envisioned as the basic unit of such a facility. The environmental chamber could be added on top or on the side.

ideal arrangement of using the track housing as a near-vacuum chamber complicates the design of the drive and support of the fly-wheel considerably. While exposed to serious dynamical strain, a pressure differential of eight psi, with the track chamber at seven psi, can be applied to test the technological reliability of the system.

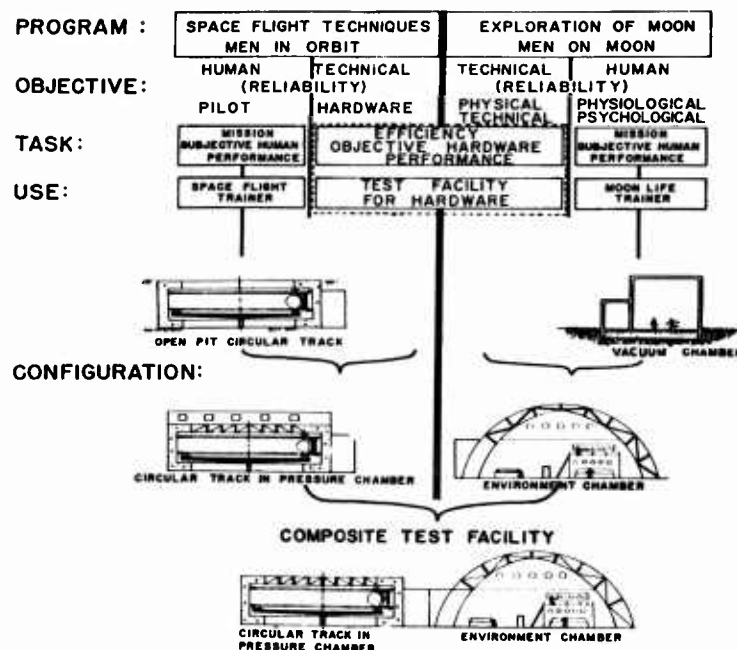


Figure 23-3. Proposed circular track - environmental chamber facility (Holloman AFB):
Anticipated use of facility.

Motion Capabilities

The maximum payload dimensions are 12 by 12 by 30 feet and the maximum payload weight (subject-system) is 50,000 lbs. For maximum payload, the load factor is 40 g.

Acceleration Profiles: For launch, a peak acceleration of 10 g and an onset time of 140 sec. are possible. For re-entry (tangential) a maximum deceleration of 30 g, a maximum payload of 50,000 lbs., and an onset time of 50 sec. are possible. For 90-degree re-entry a maximum payload of 5,000 lbs. is possible, with 320 g peak deceleration and a five-sec. onset time. Water impact simulation in the chamber is such that 40-g deceleration (peak) and 0.001 to 0.0003 sec. onset time are possible.

These acceleration profiles are understood to be reasonable test requirements rather than actual space-flight performances. Other requirements are taken care of by providing high flexibility in the accommodation of test equipment to simultaneously test the history of pressure, temperature, oscillation, vibration, noise, etc. (See Figures 23-2 and 23-3)

Control System

Details concerning the control system are not available.

Safety Features

No friction-type brake system will absorb the impulse in the short time of 0.003 seconds as required. An additional impact-type decelerator must be used to perform this requirement.

Information

For information contact Air Force Missile Development Center, Holloman Air Force Base, New Mexico.

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1. Feder, Hubert C., "Circular Track-Chamber, A Proposed Facility For Testing Man-Machine-Systems Under Conditions of Space Flight and Lunar Habitation," AFMDC-TN-60-14 report, October 1960.
2. Eslinger, N. F., and Brunauer, E. A. "Feasibility and Design Study of a Centrifuge Facility," TN-MR-9415A, August 1958, Mechanics Research Division, American Machine and Foundry Co., Chicago, Illinois.

24. WAYNE STATE UNIVERSITY VERTICAL ACCELERATOR (Wayne State University College of Medicine)

Introduction

The vertical accelerator was developed by the Wayne State University Engineering Mechanics Department. It was designed to provide controlled vertical upwards accelerations to a carriage on which cadavers, animals or humans can be placed in various positions and subjected to abrupt accelerations.

Description

The carriage consists of a modified Air Force ejection seat mounted in a frame as shown in Figure 24-1. The main features of the accelerator are shown diagrammatically in Figure 24-2. A free vertical height of 120 ft. with a cross section of approximately nine by nine feet is available for the installation. Propulsion is provided by compressed air released through a fast-acting valve to an eight-foot stroking cylinder against a piston attached to the sled. Tracks extend from the first floor to the eighth floor to guide the sled in its travel. The subject is seated so that the acceleration acts parallel to the spine of the subject.

Motion Capabilities

Maximum acceleration is 40 to 50 g's upwards depending on the weight of the subject. This results in a velocity change from 0 to 161 feet per second in eight feet in a time of 1/10 of a second. The rate of onset is adjustable from 50 g's/sec. to 1,000 g's/sec. An acceleration-time pattern is not available at the present time.

Control System

Motion of the sled can be started by manually or automatically actuating a solenoid control switch. Six pairs of hydraulic brakes, attached to the carriage, which grip the track at predetermined pressure for any desired deceleration, are used to stop the sled. The brakes are actuated shortly after the end of the piston stroke. At the top of the track a hoist is mounted to lower the sled back to starting position after it is fired.

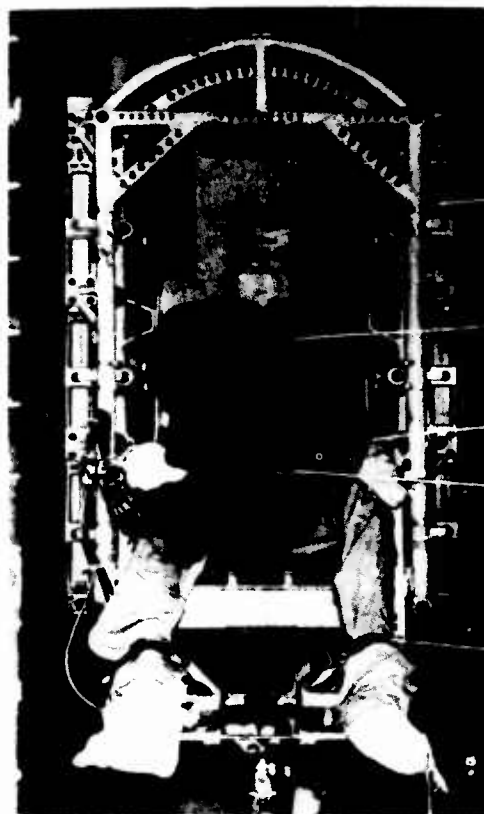


Figure 24-1. Wayne State University Vertical Accelerator: Carriage

Safety Features

The top part of the track is canted inward to act as a safety stop in the event the sled is not completely stopped by the brakes by the time it reaches the top. Also mounted near the top of the track is a safety cushion consisting of a large styrofoam log to slow the sled down in case of brake failure. Another safety feature is a cam-operated brake attached to the carriage which operates to prevent the sled from falling in case the hydraulic brakes become inoperative.

Information

For information contact Mr. Lawrence M. Patrick, Associate Professor, Engineering Mechanics Department, Wayne State University, Detroit 2, Michigan.

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report entitled, "Biodynamics Research Center Test Facilities."

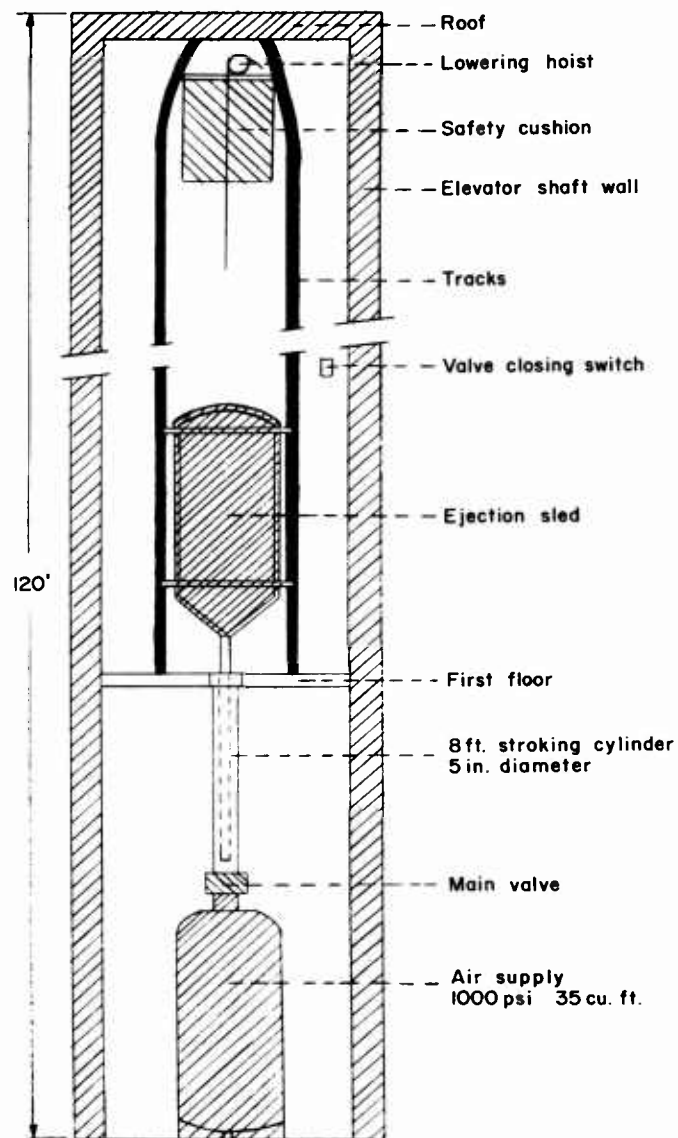


Figure 24-2. Wayne State University Vertical Accelerator; Schematic.

25. GRUMMAN VERTICAL DROP TOWER (Grumman Aircraft Corp., Bethpage, New York)

Introduction

The vertical drop tower was designed and built by Grumman Aircraft Corporation to provide a large impact facility with good reproducibility and the capability of producing a shock spectrum over a wide range. The facility has so far been used mainly for equipment testing and not for experimentation with human subjects.

Description

(See Figure 25-1) Four eight-inch diameter steel columns 50 feet long form the main structure of the tower, and are connected together by a series of steel channel diagonals. Two "V"-shaped guide rails are mounted on these channels which guide the carriage during its drop. This cart (Figure 25-2) weighs 700 pounds and is designed so that test items such as seats, electronic gear, etc., can be mounted in any orientation to the direction of application of g's. The cart is suspended by half-inch steel cables through which the decelerating loads are applied. The energy to stop the carriage is supplied by a series of hydraulic aircraft brakes operating under pressure of from 500 psi to 2,500 psi. The pressure pulse applied to the brakes depends upon the peak g required and the rate of onset desired. The carriage is dropped from a given height and falls free to a point where it interrupts an electric eye, which in turn initiates a pulse which applies the pressure to the brake system. By the variation of brake pressure impulses the g-time pattern can be varied. Photographic and electric instrumentation is available for any desired run.

Motion Capabilities

The drop tower is capable of imposing 40,000 pounds of force to a wide variety of test specimens. The rate of application ranges from any desired minimum to 4,000,000 lbs/sec. Extensive data pertaining to capabilities are not available.

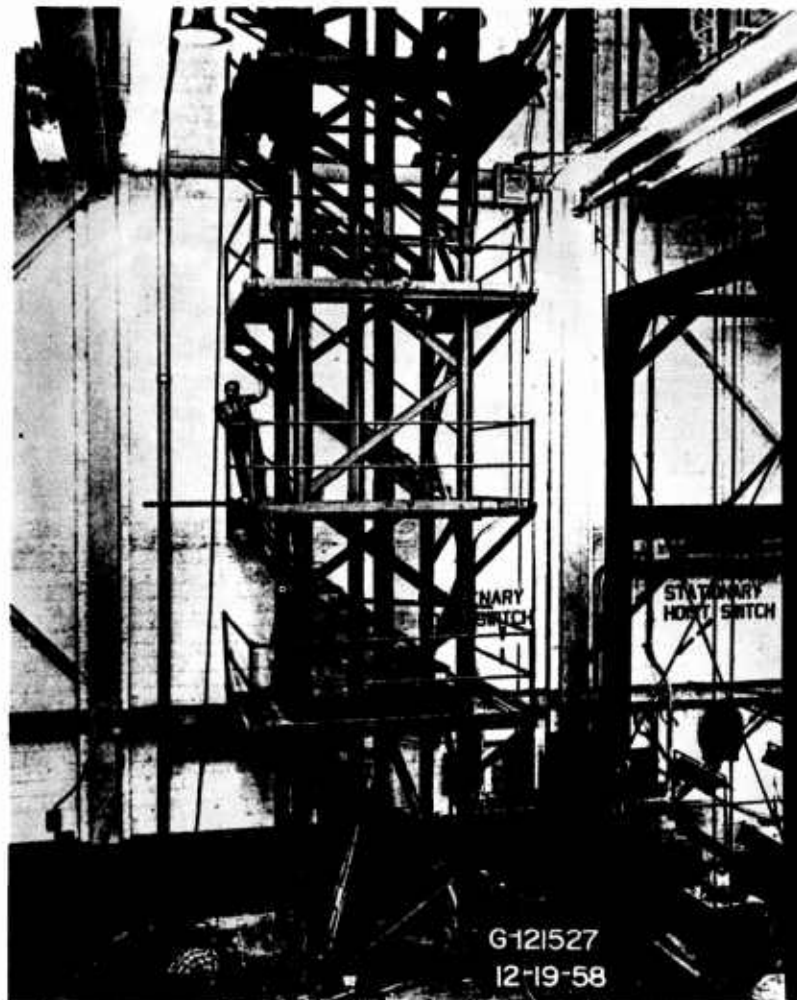


Figure 25-1. Grumman Vertical Drop Tower:
Overall view.

Control System

An open-loop system is used for control. The acceleration is determined by the height to which the test specimen is elevated.

Safety Features

In event a hydraulic or electrical failure occurs there is a mechanical method of stopping the carriage. The carriage would continue down until it engages a set of stainless steel straps. These straps are designed so that the load developed by stretching them is less than the desired test load.



Figure 25-2. Grumman Vertical Drop Tower:
Carriage with dummy.

Information

For information contact A. H. Gelderman, Environmental
Test Group, Plant 5, Grumman Aircraft Engineering Corp.,
Bethpage, New York.

26. WAYNE STATE UNIVERSITY DROP SLED (Wayne State University College of Medicine, Detroit, Michigan)

Introduction

The drop sled is an impact-test device designed by the Wayne State University Biomechanics Research Center for crash research studies. A sled guided vertically by rails is used to provide position-controlled impact of cadavers or animals.

Description

The sled is made of webbed belting interwoven across aluminum tubing. Guides attached to the sides are engaged to the vertical accelerator rails.

Motion Capabilities

The sled is raised by an electric hoist to the specified position and dropped by means of a quick release mechanism. It is guided in its fall by the accelerator rails. A drop of 120 feet is possible. Layers of styrofoam and polyurethane mounted on plywood supported by steel channels are used to absorb the kinetic energy of that part of the subject not participating in the impact. Transducers can be mounted on the subject for the purpose of recording physical reactions to impact. The 24-channel vertical accelerator recording system is used for the drop tester. Any desired velocity up to 88 ft/sec. may be attained.

Control System

A detailed description of the control system is not available.

Safety Features

When the vehicle is being raised or held in drop-height position, a safety line is attached to prevent accidental trip of the quick-release mechanism.

Information

For information contact Mr. Lawrence M. Patrick, Associate Professor of the Engineering Mechanics Department, Wayne State University, Detroit 2, Michigan.

Bibliography

Wayne State University, Engineering Mechanics Dept. report entitled, "Biodynamics Research Center Test Facilities."

27. VERTICAL DECELERATION TOWER (Wright Air Development Division, Dayton, Ohio)

Introduction

The vertical deceleration tower was designed by the American Machine and Foundry Corporation for the Aerospace Medical Laboratory to provide an impact-test facility with high reproducibility of test parameters, ease and economy of operation, large safety margins and a high rate of testing. Plans have been made to use the device for basic research on human tolerance to abrupt deceleration, and development and testing of hardware items for specific systems to protect the human body from or attenuate the forces of abrupt deceleration.

Description

Two very heavy I-beams 70 feet in length compose the major structure of the tower. These are vertically mounted in a pit 20 feet deep and consequently they extend 50 feet above floor level. On each beam is mounted a precision rail which guides the test cart during its drop. This cart, which weighs 1,950 pounds, is so designed that test items such as seats with subjects, capsules, etc., can be mounted in any orientation to the direction of application of g , which is parallel to the rails. Depending upon the peak g required and the rate of onset, this cart is dropped from a given height and falls free to floor level where a tapered plunger, approximately four feet in length and nine inches in diameter at its widest part, mounted on the bottom of the cart, enters a tube filled with water. The displacement of this fluid by the plunger produces the deceleration pattern. This pattern is controlled by three variables: the degree of taper of the plunger, the drop height, and total cart weight. By adjustment of these parameters almost any g -time pattern within the design performance of the tower can be reproduced. Because of the constancy of the force which operates the tower, i.e., gravity, and the uniformity of the deceleration, a given g -time pattern may be reproduced many times with errors of no more than five per cent of both maximum peak g and rate of onset. Electronic and photographic instrumentation is integrated with a common time base (See Figure 27-1).



Figure 27-1. The WADD Vertical Deceleration Tower: Cart in end position after drop. The deceleration tube (filled with water) can be seen under the cart.

Motion Capabilities

The drop tower is capable of imposing on test loads of up to 2,750 pounds abrupt decelerations ranging from 5 g at 150 g/sec. to 50 g at 5,000 g/sec. The impact velocity can be varied from 0-44 ft/sec. and the drop height from 0-30 feet, with 10 feet stopping distance.

Safety Features

In order to accommodate human subjects, stringent safety requirements were established upon the tower's operational sequences. The drop sequence contains several electronic safety interlocks. Of primary importance in this system is the infrared water-level sensor. It has been well established that with the hydraulic cylinder filled, the plunger will result in the required deceleration pattern. In order to eliminate the possibility of human error (failing to fill the hydraulic cylinder with water), a drop cannot be accomplished if the water level is not high enough to actuate the relay tied into the reflective infrared sensor.

A mechanical curb-arrestment device has been supplied as a safety override in case of the failure of the primary decelerator. In the event of a failure during the deceleration phase of the drop (plunger failure) a large shock-absorbing spring located above the plunger is compressed. During this time, trip-levers are thrown to allow the brake to drop out of the way and the cart to engage the mechanical override device. The device used is a

metal bender energy absorber. This equipment was manufactured by Van Zehn and Associates, Inc. of Baltimore, Maryland. Within this device stainless steel straps 3/4-inch by 1/16-inch thick are drawn. The cart energy is absorbed by a series of rollers as in a steel rolling mill. The metal bender energy absorber has been designed to arrest the cart when it is engaged at a velocity of 45 ft/sec. at a total cart weight of 2,750 lbs.

Information

For information contact Bio-Acoustics Branch, Aerospace Medical Laboratory, Wright Air Development Division, Wright-Patterson Air Force Base, Dayton, Ohio.

28. HYGES SHOCK TESTER (Wright Air Development Division, Dayton, Ohio)

Introduction

The Hyge Shock Tester from the Hyge Corporation is used by the Wright Air Development Division for the purpose of producing shocks required for testing equipment. Animal experiments on this device are planned by the Aerospace Medical Laboratory, WADD.

Description

The Hyge Shock Tester consists of a three-inch actuator, a carriage for mounting test specimens, a control panel, and a 20-foot rail system. The actuator kit includes all necessary components required to assemble units capable of producing sine-wave and square-wave shocks of various magnitudes and durations.

The actuator consists essentially of a cylinder separated into two air-tight chambers by an orifice. The upper chamber contains a piston which is seated firmly against the orifice by a low gas pressure introduced into the top of the chamber. Pressure is allowed to build up in the lower chamber, acting only on the small area of the piston seated against the orifice. When the rising pressure in the lower chamber produces sufficient force to raise the piston from the orifice, this high pressure is instantaneously applied to the entire area of the bottom of the piston, accelerating the piston, thrust column, and test carriage upward. The shock waveform is achieved by an interchangeable metering pin which controls the flow of air through the orifice as the piston is accelerated upward.

Six metering pins are included with the shock tester. Five pins were designed to produce half-sine shock pulses of 8, 11, 18, 22, and 30 milliseconds duration respectively. The sixth pin was designed to produce a squarewave shock (See Figure 28-1).

Motion Capabilities

The Hyge Shock Tester is capable of vertical movement only and will produce a shock of 15 g to 30 g peak for a specimen weight of 140 pounds mounted on the carriage.

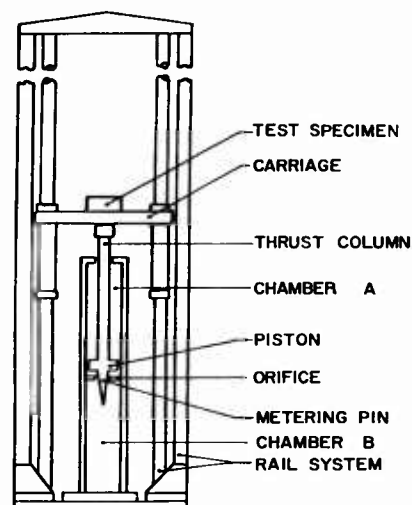


Figure 28-1. WADD Hyge Shock Tester: Schematic.

Control System

The Hyge Shock Tester is controlled by means of an open-loop system.

Safety Features

The cylinder enclosing the metering pin located between the rails limits the movement of the carriage.

Information

For information contact David L. Earls, Aeronautical Test Group, Wright Air Development Division, Wright-Patterson Air Force Base, Dayton, Ohio.

Bibliography

1. Earls, David L., "Evaluation of Hyge Shock Tester," Aeronautical Accessories Laboratory, WADD Technical Note 58-50, AD NR 150997, February 1958.

29. HG-1 EJECTION SEAT TOWER (Namatcen Naval Base, Philadelphia, Pa.)

Introduction

The ejection seat tower was designed and built by the Air Crew Equipment Laboratory, Naval Research Division, for the purpose of determining dynamic characteristics in emergency-escape systems and evaluating the physiological effects on man due to ejection forces.

Description

The device is shown in Figure 29-1. The ejection seat tower consists of a 150-foot vertical tower. A cartridge-actuated device provides the propulsion which ejects the system upward along the rails until gravity brings it to rest, at which time, dogs, attached to the seat structure, engage in ratchets secured to the tower structure, thus preventing the seat and subject from sliding down the tower. A bogey system which is manually operated engages the seat, automatically releases the dogs, and lowers the seat and subject to the ground.

Motion Capabilities

Movement is limited to the upward direction along the rails which are inclined 20 degrees from the vertical. The range of displacement of the seat is 0 to 145 feet. The device is capable of producing a velocity of 100 ft/sec., which depends upon the type of cartridge and actuator device used, the power stroke, and the ejected mass and temperature conditions. Depending upon the safe tolerance limits of the human subject, the acceleration is usually limited to 20-g maximum. For this same reason the maximum rate of onset is 250 g's/sec.

Control System

The system is manually operated by the subject operating the firing control. Velocity, acceleration and rate-of-change of acceleration is controlled prior to the firing by selecting and setting up the various parameters, such as cartridge, actuating device, power stroke, and temperature conditioning.



Figure 29-1. HG-1 Ejection Seat Tower (Air Crew Equipment Lab., Namatcen Naval Base, Philadelphia, Pa.).

Safety Features

The system contains two independently operated sets of pawls which automatically engage the ratchets on the upward trajectory and arrest the seat at the peak. One set is disengaged automatically when the bogey engages the seat structure; the other set is manually disengaged by the test subject.

Information

For information contact R. A. Bosee, Captain, MSC, U. S. Navy, Director of Air Crew Equipment Laboratory, Namatcen Naval Base, Philadelphia 12, Pa.

Bibliography

1. "Dynamic Responses in the Ejection Seat System," TED Nam 256005, Report No. 5, August 7, 1947.
2. "Military Specifications, Seats, Ejection, Airplane, Design and Installation," Mil-S-1847 (Aer), February 16, 1955.
3. "Investigation, Design and Development of an F7U-3 Ejection Seat Energy Absorption System for Reduction of Crash Force-loads," NAMC-ACEL-335, June 24, 1957.

30. "PILE DRIVER" (Proposed)
(Naval Air Development Center, Johnsville, Pa.)

Introduction

A 600-foot "Pile Driver" has been proposed by Johnsville NADC and studied by McKiernan-Terry Corporation for the purpose of studying man's physiological performance when he is subjected to extremely high impact loads encountered during crashes and high-speed ejection from aircraft. "Pile Driver" should be capable of providing multiple, programmed bounces of the "hammer" in order to imitate crashes involving skipping across the ground.

Description

(See Figure 30-1) The base of the drop tower consists of a building approximately sixty feet high by eighty feet square. The upper portion of the tower is approximately 540 feet tall, of open-space frame construction that is laterally supported by guy wires. The entire weight of the guy tower will be supported by the truss supports that rest on bearing pads so that it will be isolated from impact shock which will occur in the sixty-foot building.

The sixty-foot height of the building at the base of the tower is the length of the arresting stroke for the drop capsule, and it contains the crushing device for varying the impact load on the human subject from 10 g to 1,000 g.

In a typical test, the drop capsule and its human subject are raised to the top of the 600-foot tower by an overhead winch. The capsule is then released to fall 540 feet into the arresting gear at the base of the tower.

The arresting gear that is shown in the attached drawing consists of a ring of water nozzles that are placed in the wall at the bottom of the arresting shaft. There would be approximately 20 nozzles that would receive water under high pressure from an accumulator storage system fed by two motor-driven pumps.

In a typical test, high-pressure water would be ejected from the nozzles straight up the arresting shaft so that it strikes the bottom surface of the drop capsule as it enters the 60-foot arresting

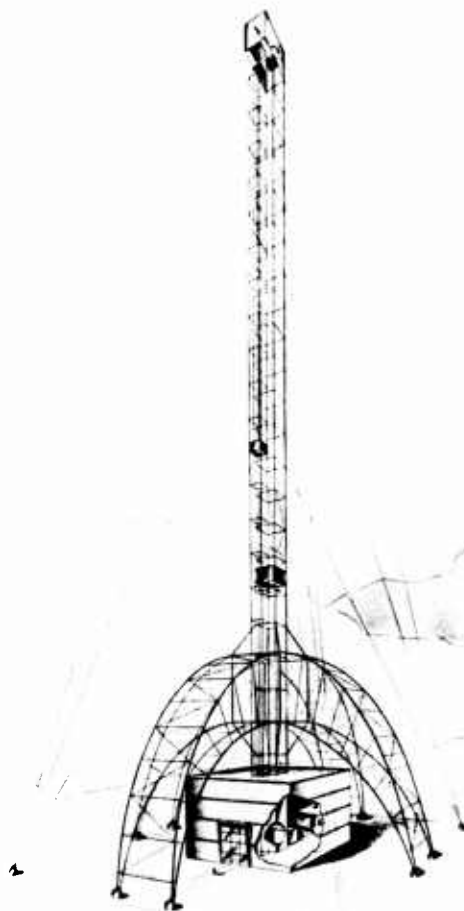


Figure 30-1. NADC's proposed "Pile Driver"
(artist's conception)

shaft. The bottom surface of the capsule has the form of two typical reaction turbine blades such that the impingement of the high velocity water stream from the nozzles on the blades produces a decelerating force on the capsule. As the capsule descends into the arresting shaft, it is decelerated until it is stopped by the essentially constant-velocity, constant-mass water system.

With this type of arresting system, the maximum deceleration force can be varied from 10 g to 1,000 g by controlling the velocity of the water stream as it is ejected from the nozzles and by varying the size and number of nozzles. If it is desirable to increase the

deceleration time for a given test, beyond the time that is required for the capsule to decelerate at the bottom of the shaft, sufficient energy can be stored in the water-jet system so that the capsule will rebound to some predetermined height in the drop tower.

In a test where the capsule is thrust upward into the tower, it will be necessary to arrest the capsule when it reaches the peak of its rebound cycle. Since it is possible that the capsule could presumably rebound up to any point in the full height of the tower, it will be necessary to equip the tower for its full height with a series of arresting pawls. These pawls can rotate a full 90 degrees from horizontal to vertical and they would probably be actuated by electrical or hydraulic means suitably interlocked for safety.

Motion Capabilities

The "Pile Driver" is capable of only vertical motion through a maximum distance of 600 feet. Deceleration of 10-1000 g can be achieved by varying the dropping height to which the gondola is elevated between 10 and 600 feet. A 5,000-lb. payload should be considered a maximum for the "Pile Driver."

Control System

An open-loop control system will be employed during the operation of the "Pile Driver."

Safety Features

At the base of the drop tower, emergency air chambers will be included in the building design to afford safety devices in the event of failure of the arresting mechanism or of the elevator cable system.

Information

For information contact Aviation Medical Acceleration Laboratory, U. S. Naval Air Development Center, Johnsville, Pa.

Bibliography

1. Aviation Medical Acceleration Laboratory report entitled, "Four Proposed Motion Simulators," U. S. Naval Air Development Center.

31. NAVAL ORDNANCE TRACK (China Lake, Calif.)

Introduction

The naval ordnance test track was built by Michaelson Research Laboratory for the purpose of testing simulated catapult launchings and arrested landings.

Description

The supersonic research track is 4.1 miles long. The track is a precision instrument and is aligned within 0.6 inches horizontally and 0.036 inches vertically, affording a minimum of lateral and vertical accelerations at high speeds. The track rails are 171-pound crane rails set at standard railroad gauge of four ft. by 8 1/2 inches. The rails are joined by heavy dowels and are imbedded in heavy H-shaped reinforced-concrete continuous beams. Associated with this track is an assembly unit for constructing sleds and mounting test equipment. A test control building provided with the latest telemetering and recording equipment is located near the breach of the track. A rocket unit is available for providing necessary types of rockets for different acceleration patterns. Available also at the track site are high-speed camera units, instrumentation units and data-reduction units.

Motion Capabilities

The track is arranged for either two-rail or mono-rail sleds and is capable of projecting a 20,000-lb. payload with an acceleration of 10 g to a maximum velocity of 1,000 feet per second. No data pertaining to deceleration are available.

Control System

The device is manually initiated, with the desired acceleration being pre-determined.

Safety Features

The sled is arrested by means of a braking system applied to the rails.

Information

For information contact Michaelson Research Laboratory,
Naval Ordnance Test Station, China Lake, California.

Bibliography

1. "Description of the Naval Research Supersonic Track,"
Naval Ordnance Track Report No. 880, July 1954.

32. HG-1 LINEAR ACCELERATOR (Namatcen Naval Base)

Introduction

The HG-1 linear accelerator is a horizontal catapult device designed and built by the Air Crew Equipment Laboratory, utilized for research and development projects concerning crash protection and dynamic evaluation of structural and restraint systems and cockpit equipment.

Description

(See Figures 32-1 and 32-2) The accelerator consists of a sled and 380 ft. of rails. The accelerating energy is obtained from the expansion of a fixed air mass entrapped in an accumulator. The mass is sealed in the accumulator by a piston plunger and the force exerted by the air mass is counterbalanced by hydraulic fluid under pressure which is dumped to initiate the firing cycle. The test vehicle is arrested following runout.

Motion Capabilities

The HG-1 catapult has one degree of freedom in the horizontal direction. A seven-foot six-inch power stroke provides the acceleration to the sled, which travels an additional 25 feet to the arresting gear cable. The sled engages the cable and is arrested within 125 feet. The maximum velocity obtained through this distance is 140 feet per second. The maximum acceleration produced is approximately 43 g's, which is controlled by regulating the hydraulic pressure. The rate of change of acceleration is approximately 1,075 g's/sec.

Control System

The control system is manually initiated, starting a firing sequence which automatically activates in proper order the controls, lights, cameras and actual catapult firing. The firing valve is opened electrically, thus permitting high-pressure air from the control-valve accumulator to move the control valve piston, thus opening the valve outlet port. With control valve port open, the high-pressure oil in the poppet is free to flow out of the port leading to the sump tank, thus releasing the pressure behind the poppet piston.

The position, velocity, acceleration and rate of change of acceleration are controlled prior to the firing by adjusting the piston stroke and the air pressure in the accumulator. The magnitude of the acceleration is controlled by the air pressure. The duration of the acceleration may be decreased by reducing the piston stroke.

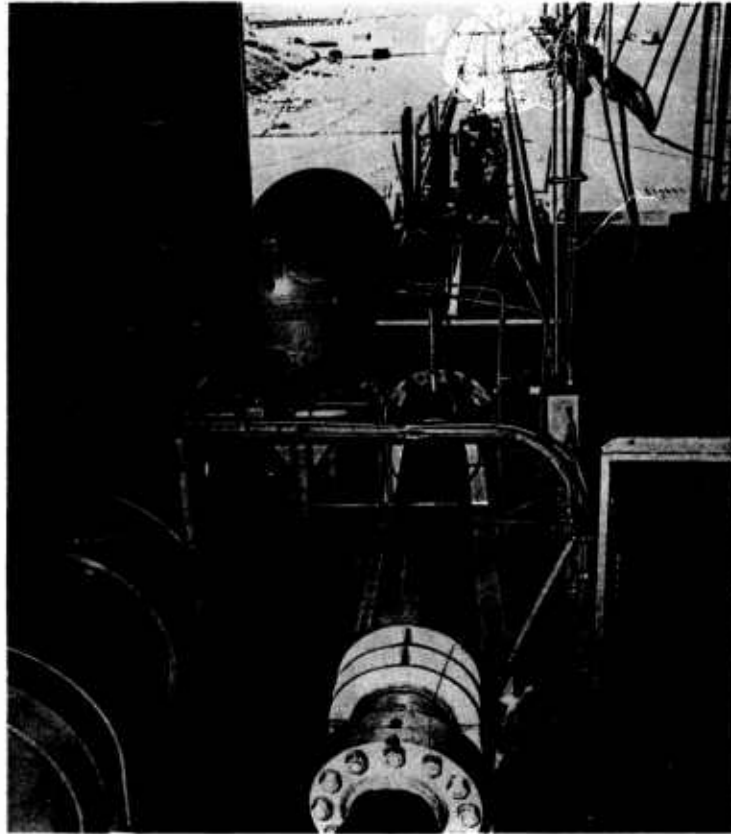


Figure 32-1. HG-1 Linear Horizontal Accelerator
(Namatcen Naval Base, Philadelphia, Pa.):
Test vehicle in firing position.

Safety Features

A steel control tower with safety glass protects the firing control personnel and affords a view of the entire area. The catapult operator is protected by a steel cage and the instrumentation is enclosed behind a block wall.

Information

For information contact R. A. Bosee, Captain, MSC, U.S. Navy, Director of Air Crew Equipment Laboratory, Namatcen Naval Base, Philadelphia, Pa.

Bibliography

"Description of Present Motion Simulators" by the Air Crew Equipment Laboratory, Namatcen Naval Base, Philadelphia 12, Pa.

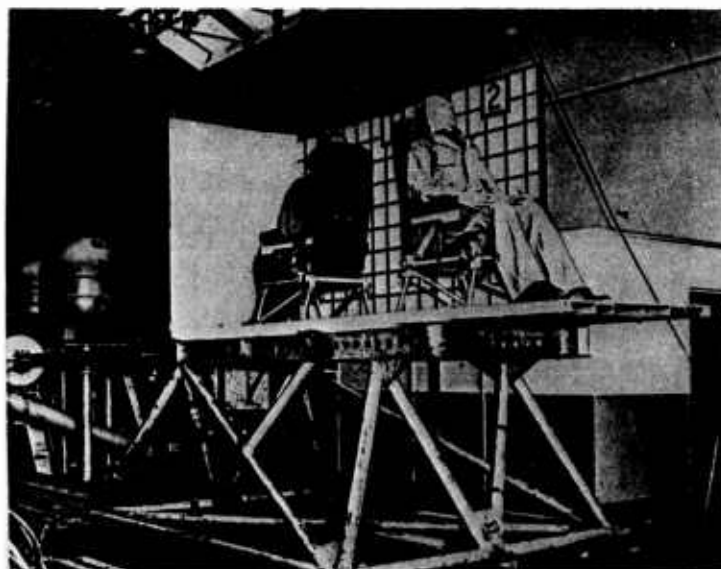


Figure 32-2. HG-1 Linear Horizontal Accelerator
(Namatcen Naval Base, Philadelphia, Pa.):
View at start position.

33. THE DAISY DECELERATOR (Holloman Air Force Base, New Mexico)

Introduction

The Daisy Decelerator has been developed for controlled abrupt-deceleration studies. It has been used with human subjects and animals to establish tolerance to mechanical impact in support of bioastronautic requirements and general crash research. Another decelerator, the "Bopper," at the same location, is used for low force level indoctrination of subjects and for research supporting the program on the Daisy Accelerator. The "Bopper" is an elastic-cord powered device (up to 25 G). For acceleration patterns exceeding the capability of the Daisy Accelerator, the Holloman High-Speed Track, 35,000 ft. long, is available.

Description

The Daisy Decelerator consists of a horizontal track, a sled, an air gun for gradual, smooth acceleration, and continuously variable water brakes. Various brake mechanisms have been used at different times. (Ejection seat cartridges were used in earlier times for acceleration.) Three sleds are available for use on the decelerator.) The subject can be oriented in any direction with respect to the horizontal impact vector.

Motion Capability

The new air gun allows smooth acceleration to any velocity between five and 175 feet/sec. Sled impacts up to approximately 40-G plateau, 4,000 G/sec. rate of onset and plateau duration of up to 50 msec. have been used in human experiments conducted so far. The capability of the brakes is still higher; the program calls for the study of impacts with 80-G peak and 10,000 G/sec. rate of onset.

Control System and Safety Features

See under Information.

Information

Aeromedical Field Laboratory, Air Force Missile Development Center, Holloman Air Force Base, New Mexico.

This description of the Daisy Track is unfortunately incomplete since a detailed description and the report cited below are not available!

Bibliography

1. Beeding, E. L., Jr., "Daisy Track and Supporting System," HADC Technical Note, June 1957.

34. HURRICANE SUPERSONIC RESEARCH SITE (Hurricane Mesa, Washington County, Southwestern Utah)

Introduction

To keep pace with the mounting problems of escape from high-speed aircraft, the United States Air Force has conceived the hurricane supersonic research site, formerly known as the supersonic military air research track, as an important part of the effort toward higher equipment efficiency and a deeper understanding of the needs and limitations of the human element in supersonic flight. The facility was developed by the Coleman Engineering Company, Turrance, California.

The main purpose of the facility is to test ejection from supersonic flight through the live operational sequence: ejection, seat stabilization, windblast, and parachute opening. The ejected objects fly over a cliff located at the end of the track allowing 1,500 feet of vertical fall into a valley. The sled is stopped at the end of the track at the extreme edge of the valley. The facility has been used with chimpanzees and dummies, but not with human subjects.

Description

(See Figure 34-1) The hurricane supersonic research site, located atop Hurricane Mesa, extends for 3 1/2 miles and provides adequate room for both track and its supporting functions. The track is actually 12,000 feet long; however, a 5,000-foot extension is proposed.

The two 12,000-foot rails are composed of U.S. Steel 105-pound/yard crane rails in standard mill lengths of 39 feet. Continuously welded throughout, they are laid on a reinforced concrete foundation-girder structure which is based on bedrock. Standard railway gauge, 56-1/2 inches between the inside faces of the rail balls, is employed. This particular rail section was chosen since it offers a high static and dynamic load capability.

The test vehicle consists of a sled which is capable of carrying a seat with dummy, animal or other test article, along with appropriate instrumentation, and a locomotive or propulsion section. Both ride on rail-gripping slippers mounted upon aerodynamically faired beams which are built into the bodies of the carriages.



Figure 34-1. USAF's Hurricane Supersonic Research Site.

A 2,800-foot water brake is profiled on a numerically faired curve which has a minimum radius of curvature of 400,000 feet. Accurate control of varying water levels and extension of the braking area to 5,000 ft. are both made possible by the use of frangible dams.

The instrumentation system is equipped to simultaneously transmit and receive on three separate telemetry systems, each of which is capable of carrying twelve channels of information. This permits undertaking such complex operations as the simultaneous ejection of two dummies from a dual-seat bomber simulation with data transmitted from both test figures. At the same time, it is possible to also gather aerodynamic pressure information, structural load data, accelerations, temperatures and various other intelligences through the medium of sled-mounted packages.

Motion Capabilities

The track has been designed to obtain speeds up to 6,000 ft/sec.

Deceleration is achieved by introduction of a water scoop which transfers the liquid, into which it has been lowered, through a vertical arc of approximately 180 degrees before discharging it in a forward direction. Braking momentum is thus derived by

transfer of energy to the liquid medium, and the download from the scoop is taken out by a third rail which lies along the bottom of the trough at centerline.

Complete halting of the vehicle is accomplished by a hydraulic arresting gear which lies in the final 150 feet of the water brake area. Its design load capability is 15,000 lbs. at a maximum velocity of 200 feet per second.

Vertical ejection accelerations depend on the particular ejection system mounted on the sled.

Control System

All firing controls are located on the console in the blockhouse. These include indicator lights, automatic sequence timer, reset button, firing switch, and the arming switch which is cut into the circuit as the last operation before actual firing. Circuits go to the launching pad, then along a control and communications cable paralleling the track. Terminal blocks are located at intervals of 400 feet to permit plugging in the firing trailer which is used with solid propellant rockets, thus establishing the control and communications circuits from any such point which has been predetermined as the start of the test run.

Safety Features

A system of loudspeakers audible over the entire area employs one speaker mounted on the blockhouse, one on top of the muzzle and crew revetment. In addition, at points 4,000 feet and 8,000 feet along the track, two speakers mounted back-to-back are used at each location. This loudspeaker arrangement is supplemented by sirens situated at the various speaker stations with their control switch, along with the control and microphone for the loudspeakers, located on the firing console.

Information

The facility is scheduled to be inactivated (stand-by basis) by mid-1961, since at the present time no immediate requirements for its use exist.

For information contact Mr. Ross Seger, Track Branch, AF Flight Test Center, Edwards AFB, California.

35. LONG HOLLOMAN TRACK (Holloman Air Force Base, New Mexico)

Introduction

The purpose of this facility is to subject missile and space-vehicle components to the physical forces of acceleration and vibration encountered in operational situations. This test facility is also useful for a variety of other research programs, such as biological experimentation in the biodynamics of manned space flight.

Of all the captive missile test tracks in existence, that of the Air Force Missile Development Center at Holloman Air Force Base, New Mexico, is the longest and one of the most carefully engineered.

Description

(See Figures 35-1, 2, 3) The foundation already in place for the old track was used as part of the 35,000-foot track, but all

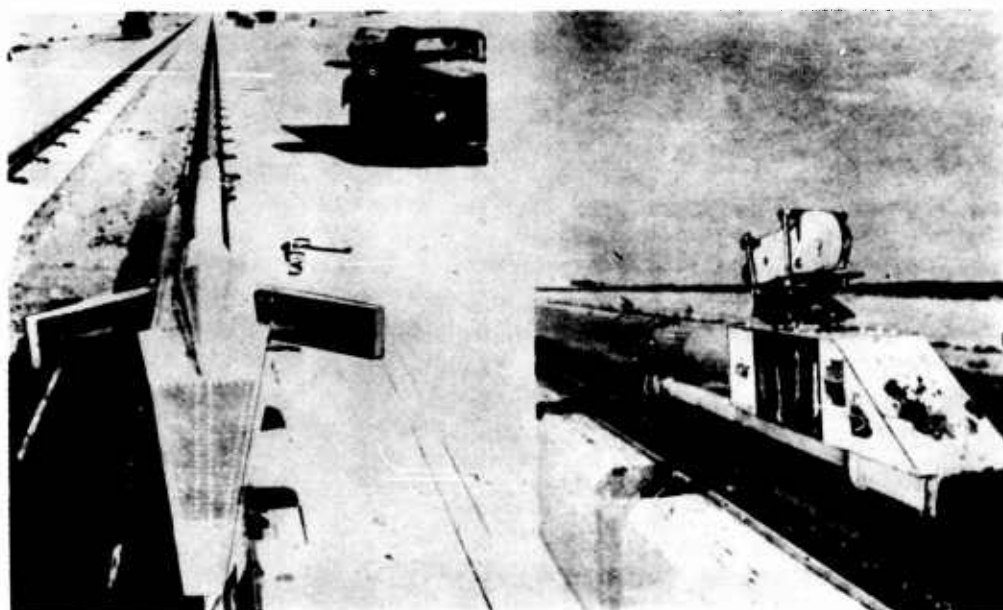
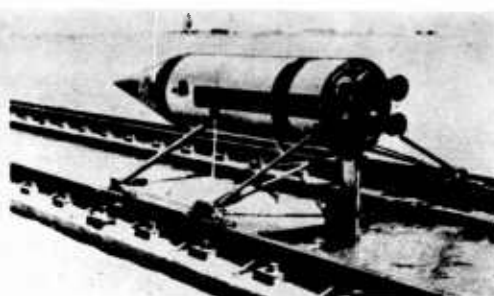


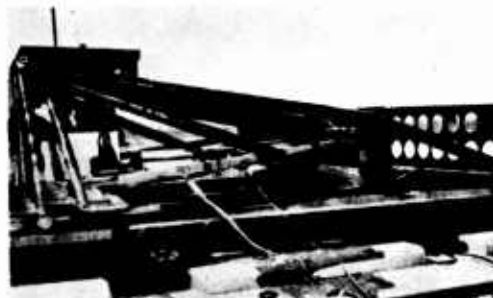
Figure 35-1. Long Holloman Track: Left: Northrop Monorail (AFMDC 5903), Air Brakes Open. Right: Camera-carrying standard mono-rail (AFMDC 5804) dented and splattered by bird impact.



I-BEAM SLED



AIRCRAFT ARMAMENTS SLED NUMBER TWO

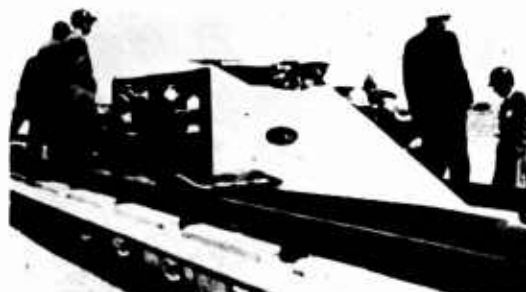


GAM-47 SLED



AIRCRAFT ARMAMENTS SLED NUMBER ONE

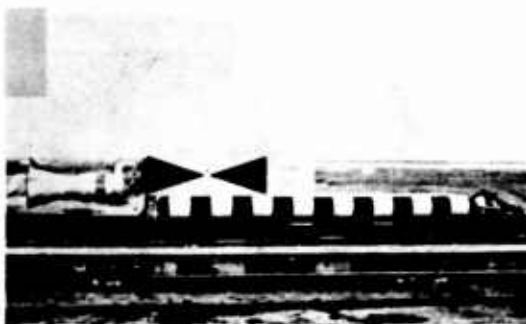
Figure 35-2. Long Holloman Track: Various sled configurations.



COLEMAN SLED



RS-2 SLED



RS-1 (SMALL LOX) SLED



RS-2 IN ACTION

Figure 35-3. Long Holloman Track: Various sled configurations.

existing rails were replaced. Specifications called for the use of 171-pound crane rails, spaced seven feet apart as in the old track but forge-welded this time into continuous lengths. The continuous-weld technique was not unprecedented and was intended to eliminate the excessive vibration caused by passing over rail joints at high speed, but it was still one of the features that the Center had to defend against those persons who sought to make the track specifications less rigorous. The problem of expansion and contraction of the rails with changing temperature was solved by pre-stressing before final tie-down; they were stretched a total of more than twenty feet so that the metal would be at a tensile force equivalent of 440,000 pounds at zero degrees fahrenheit or zero tension at 120 degrees.

The track consists basically of a steel-reinforced concrete, U-shaped girder upon which precisely aligned, continuous-welded rail has been mounted.

It is slightly over 35,071 feet in length. Moreover, the trough for water-braking (with slots to hold the frangible dams set every ten feet ten inches) now extends the entire length of the track, which had not been the case before.

Several other important elements of the new track complex include: three blockhouses, each with a complete firing circuit, a data-collection/telemetry building, seventy-two instrumentation pads spaced at fifty-foot intervals along a line 1,040 feet east of the track, to be used either as fixed-camera mounts or as other instrumentation sites, and a velocity-measuring system of unprecedented accuracy, especially designed for guidance testing.

"Water sausages" and "bath tubs" have been developed as braking methods for mono-rail use. Some effort has been spent on development of a retractable water-brake scoop, designed to eliminate the drag if not the weight of conventional braking scoops.

A number of sleds have been developed and tested. Several of these are shown in Figures 35-2 and 35-3.

Motion Capabilities

The motion capabilities are a function of the sled used rather than the track itself. The most advanced of Holloman's multi-purpose solid-booster test sleds (AFMDC 5801) was designed to carry 1,000 pounds of payload or to push a forward vehicle carrying a payload of 2,000 pounds. By using different types and numbers of solid boosters, it was to have a thrust range all the way from

5,000 to over 300,000 pounds and to be capable of 50-g acceleration with top speed above 3,000 ft/sec. The sled came with two different fibre-glass nose sections; its empty weight was 3,180 pounds. Sleds have been designed for both dual-rail and mono-rail operation.

Control System

The Holloman track's 32-channel PCM telemetry system is the first of its type installed anywhere for track instrumentation.

Each of the three-track blockhouses is equipped with sleds to be fired from intermediate points as well.

The track instrumentation complex includes closed-loop television to permit observation of a sled just before firing, when personnel have had to leave the track vicinity, and a wide variety of specialized transducers.

Safety Features

With the complete telemetry system the sleds may be stopped at any point along the track. A stopping distance of 400 feet is required.

Information

For information contact Air Force Missile Development Center, Holloman Air Force Base, New Mexico.

Bibliography

"History of Tracks and Track Testing 1949-1960" at the Air Force Missile Development Center, Holloman Air Force Base, New Mexico, Volume II by David Bushnell.

36. LINEAR DECELERATOR (Edwards Air Force Base, Calif.)

Introduction

A linear decelerator carriage has been designed especially to give controllable and reproducible deceleration time patterns. This deceleration device was used in the pioneer studies to supply urgently needed, accurate information concerning the effects on the human body due to dynamic forces of short duration encountered in crash-type decelerations. The following describes the facility used in the early studies by Col. Stapp (1949). In the meantime, the Edwards Sled facilities have been modified and improved.

Description

(See Figure 36-1) The equipment consists essentially of a 1,500-lb. carriage propelled along a rail track by as many as four 1,000-lb. thrust solid fuel rockets. Deceleration is produced by friction brake shoes acting on two heels mounted under the carriage. Deceleration-time patterns are controlled by pressure on the brake shoes, the number and sequence of brakes set, and the velocity of the cart on acting on the braking system. The decelerator with subject in position for forward-facing run and backward-facing run is shown in Figure 36-2.

Motion Capabilities

The cart is limited to motion in the horizontal plane. The subject may be oriented on the sled at will. Forward-facing and backward-facing runs have been studied most. Experiments have been performed producing rates of change of deceleration up to roughly 1,400 g/sec. Levels of 50 g have been obtained by 5-g intervals for plateau durations ranging between 0.15 and 0.42 seconds.

Information

Track Branch, AF Flight Test Center, Edwards AFB,
California.

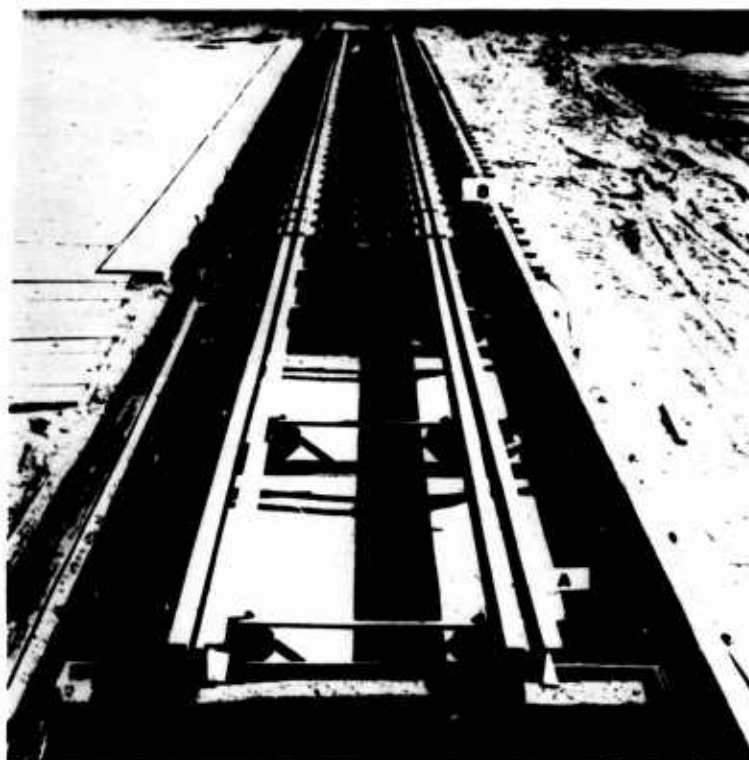


Figure 36-1. Linear Decelerator (Edwards AFB):
Close-up of brakes, looking down the track:
A. Guides for brake keels into brakes.
B. 45 sets of brakes.

Bibliography

J. P. Stapp, "Human Exposures to Linear Deceleration,"
AF Technical Report No. 5915, June 1949.

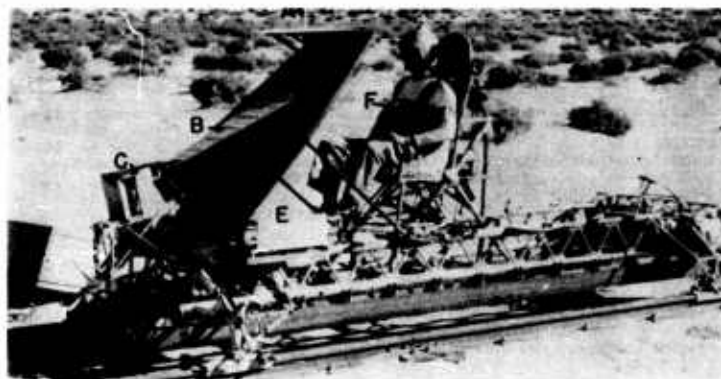


Figure 36-2. (A) Decelerator with subject in position for forward-facing run. (a) Telemetering antenna (b) Windshield (c) Movie camera (d) Slipper (e) Telemetering equipment (f) Chest accelerometer (g) Shoulder strain gauge (h) Braking keel.



Figure 36-2. (B) Decelerator with subject in position for backward-facing run. (a) Foot rest (b) Chest accelerometer (c) propellant rockets (d) Vertical hand hold.

37. CATAPULT AND ARREST ACCELERATION SIMULATOR (proposed)

(All American Engineering Co., Du Pont Airport,
Wilmington, Delaware)

Introduction

A design study was performed by All American Engineering Company to determine the feasibility of simulating the longitudinal and vertical accelerations encountered by crew members in catapulting and arresting carrier-based aircraft. After enduring the desired acceleration-time history, the subject is presented the task of correcting disturbances in pitch and roll gyros with flight controls. The catapult and arrest acceleration simulator will be designed to provide the high rate of onset of acceleration not possible with existing centrifuges, and to provide a more economical test than that possible with a rocket-powered sled.

Description

(See Figure 37-1) The complete test device will consist of a test vehicle with brakes, a jet car to propel the vehicle, and suitable horizontal tracks to guide and brake the test vehicle and jet car.

The test vehicle is supported by aircraft wheels rolling on top of the guide rails. The capsule for the subject is attached to a supporting frame that is hinged at the rear of the test vehicle and has a spring near the front of the vehicle so that some vertical motion may be obtained at the capsule. This is shown in Figure 37-2.

The test operation starts with the jet car and test vehicle at battery position; the spring is deflected to the required position to produce the desired vertical acceleration-time history. After having reached full speed the jet car is stopped, and the test vehicle coasts to the point where the acceleration-time history is applied. The force required for the horizontal acceleration is a result of friction applied to the guide rails by the electro-hydraulic brake attached to the sled. A valve and accumulator serve the function of supplying just sufficient hydraulic fluid to the brake system immediately prior to the start of the acceleration program to bring the brake pucks close to the brake rail.

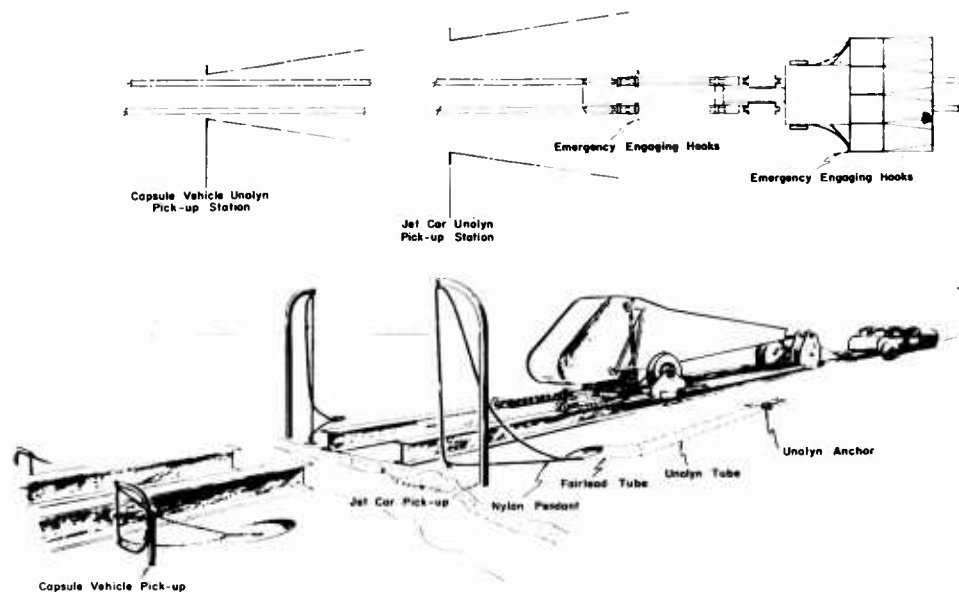


Figure 37-1. The Catapult and Arrest Acceleration Simulator (proposed): (All American Engineering Co.)

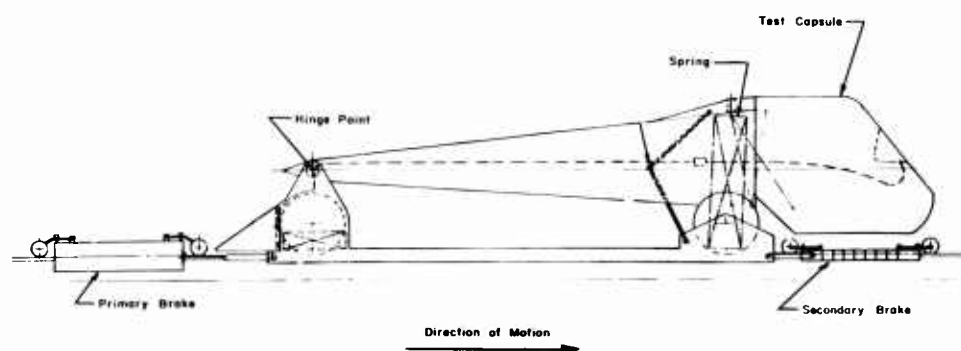


Figure 37-2. The Catapult and Arrest Acceleration Simulator (proposed): Test vehicle.

The flight control task is presented to the subject after completion of the acceleration program, and his performance is measured. Physiological measurements are taken during the test run, and either recorded on a vehicle-mounted oscillograph or telemetered to a recording station.

The payload of the test device as designed is 300 lbs. This could be increased if desired with little proportionate effect on the total capabilities of the system.

Motion Capabilities

The upper limit of negative horizontal acceleration is 15 g's and 100 g's/sec. rate of onset. The duration of acceleration is limited by the maximum velocity that can be obtained and the length of track available to apply the acceleration program. A forecast catapult and arrest-time history is presented in Figure 37-3. A velocity of 210 knots can be obtained through a 500-foot length of acceleration program.

The vertical acceleration-time history will be basically one of damped harmonic motion. The initial rate of onset of acceleration is a function of spring deflection, spring mass, and the natural frequency of the structure between the spring and the subject. After the first quarter cycle, the motion of the subject will be a function of the spring force and the oscillating mass. The maximum vertical stroke is two feet.

Pitch rotation on the order of 3 degrees per two-foot vertical stroke is present during vertical motion as a consequence of the method of restraint. All other motions are ideally reduced to negligible values.

Control System

The control system for the brake producing the horizontal acceleration is of the electro-hydraulic type. The hydraulic pressure is delivered to the brake, producing a friction drag force proportional to the hydraulic pressure.

When it is desired to start the vertical acceleration program a signal opens the valve allowing flow between opposite sides of the hydraulic cylinder and into the reservoir. The valve will be closed when vertical acceleration is zero, and it is desired to end the vertical acceleration program; the signal to start and stop the program is initiated by the function generator in the horizontal motion control

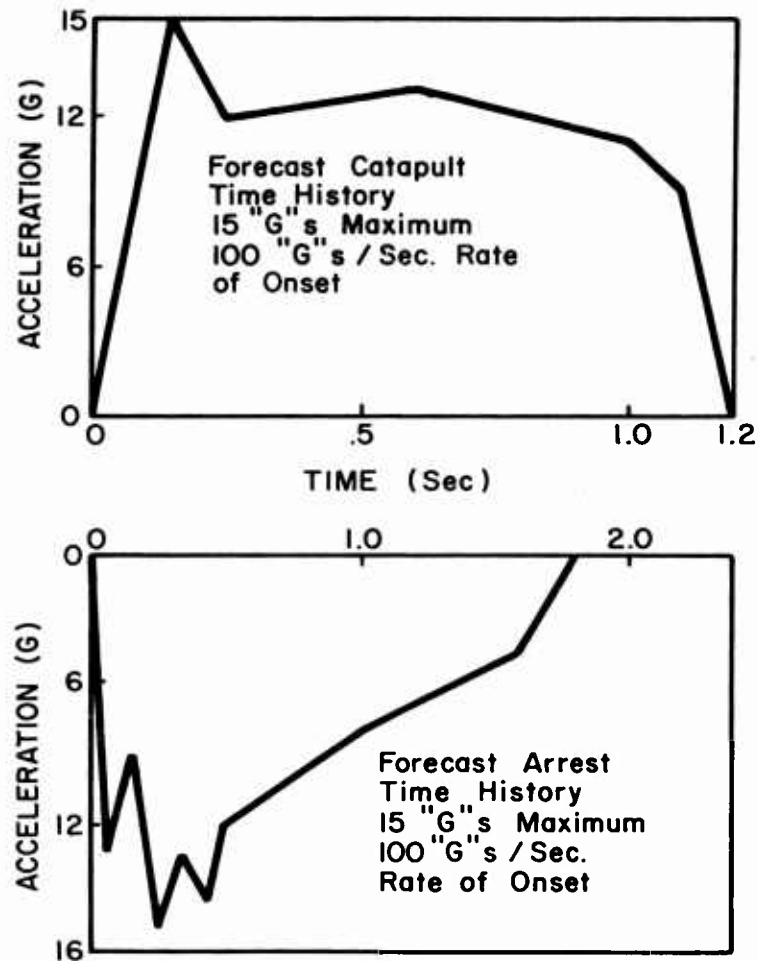


Figure 37-3. The Catapult and Arrest Acceleration Simulator (proposed): Forecast catapult and arrest longitudinal acceleration-time history.

system. The consistency of the vertical acceleration is assumed to be such that closed-loop control as used with horizontal motion will not be necessary.

Safety Features

The safety of the test subject is dependent upon safe arrest of the test vehicle and jet car. The primary means of stopping the

jet car is a series of brakes towed by the jet car that are applied by running onto a thickened portion of the guide rail.

The test vehicle is designed so that failure of the primary suspension means will not allow the vehicle to come free of the guide rails. Therefore, all brakes will have the opportunity to arrest the vehicle.

Information

For information contact Robert Lees, All American Engineering Company, Du Pont Airport, Wilmington, Delaware.

Bibliography:

1. Brown, J. L., Elles, W.H.B., Webb, M.G., and Gray, R. F., "The Effect of Simulated Catapult Launching on Pilot Performance," U. S. NADC Aviation Medical Acceleration Lab., Johnsville, Pa. Report No. NADC-MA-5719, 31 December 1957.
2. Lees, R. and Green, H.S., "Catapulting and Arresting Physiological Simulator (CAPS)," Design Study Report, All American Engineering Company, Wilmington 99, Delaware, Report N-469.

38. HORIZON PROJECTOR (NASA Ames Research Center, Moffett Field, Calif.)

Introduction

The horizon projector was designed by the National Aeronautics and Space Administration Ames Research Center for the purpose of studying man's reaction to various flight conditions. Included among such studies are lateral-directional stability criteria and certain landing approach and longitudinal control studies. The projector consists mainly of a glass hemisphere.

Description

(See Figure 38-1) The projector consists of a glass hemisphere enclosing a light bulb with the light being projected in such a manner that the edge of the hemisphere forms a horizon on the inside of a 20-foot diameter spherical dome enclosing the projector and cockpit. The hemisphere and light bulb are moved with electromechanical position servos.

Motion Capabilities

The glass hemisphere can be rotated at a velocity of eight rad/sec. to move the horizon in roll and yaw directions. Pitching motions of the horizon are achieved by moving a light bulb up and down. The natural frequencies of these motions are approximately three radians per second. Horizon angular travel is limited by the servo drives which can be varied depending upon the components utilized.

Control System

The horizon projector is designed to operate in a closed-loop manner. Signals from the pilot's controls are fed into a general-purpose electronic analog computer. The computer is programmed to provide solutions of the airplane control system, airframe dynamics and problem geometry. The resulting pitch, roll, and yaw angles are used to drive the horizon projector.

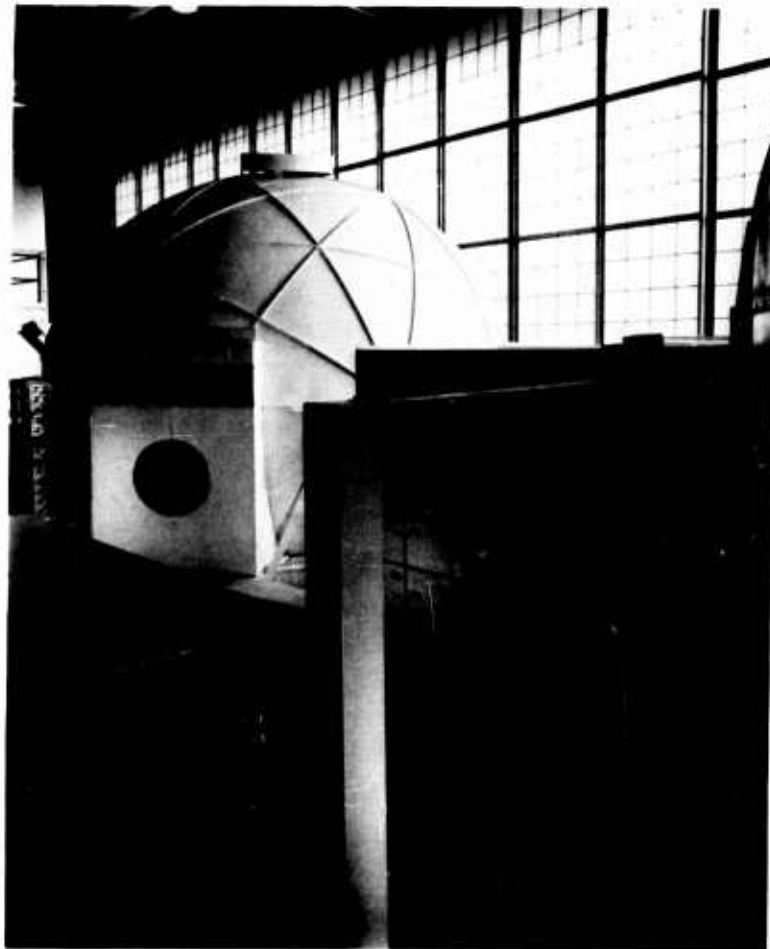


Figure 38-1. NASA Horizon Projector.

Information

For information contact Flight Research Branch, Ames Research Center, Moffett Field, California.

Bibliography

No reports on studies conducted with this facility have been published as of this time.

39. F-151 OPTICAL SIMULATOR

(National Aeronautics and Space Administration,
Ames Research Center, Moffett Field, Calif.)

Introduction

The F-151 Optical Simulator is a vehicle designed and built by Ames Research Center for the purpose of simulating the optical stimulus man would receive if he were flying an actual craft.

Description

(See Figure 39-1) The subject is seated in the simulated vehicle cockpit in the center of a hemispherical projection screen. A reproduction of the view from the cockpit is projected onto the screen. The scene is generated by televising the image of an extremely small model of the "outside world," the camera angle and range, with respect to the model, such that the perspective from the pilot's point of view is accurately simulated. The camera-model orientation is controlled by signals from an analog computer which solves the kinematic equations of the particular problem being investigated.



Figure 39-1. NASA's Optical Simulator.

Motion Capabilities

The range of optical field motion is a function of the model. For example, if the model is a target airplane the range of motion is infinite. If the model is a ground scene the range is limited by the extent of the model. The simulator is presently being set up and no data are available on maximum performance.

Control System

The control system can be varied to represent almost any type of vehicle. The response of the simulator would be in accordance with the response of the simulated craft. The control system is a closed-loop type, since the pilot actually "flies" the craft.

Safety Features

There is little danger of physical injury from this simulator. There is X-ray shielding between the cockpit and the television projection tube.

Information

For information contact Flight Research Branch, NASA, Ames Research Center, Moffett Field, California.

40. BOEING FLIGHT SIMULATOR FACILITY (Boeing Airplane Systems Laboratory Unit, Wichita, Kansas)

Introduction

The Wichita Division of the Boeing Airplane Company has developed several flight simulators. The simulation techniques and facilities are adaptable to many flight and navigational situations, requiring only mock-up of the specific desired airplane station, and insertion of specific airplane performance equations into the computers.

Boeing Wichita has applied the flight simulation concepts to such problems as low-level flight control and navigation, and to display-control problems under varied vibration environment.

Pilot's Flight Simulator

Description

(See Figure 40-1) The pilot's station simulator is a wood, metal, and cloth, field-scale mock-up and is equipped with the following instrumentation: Radar scope with both profile and plan display capability, horizontal reference and fuselage reference line stabilization modes, altitude indicator with pitch and roll capability, clearance plane indicator, airspeed indicator, directional gyro, barometric altimeter, accelerometer, and radar altimeter.

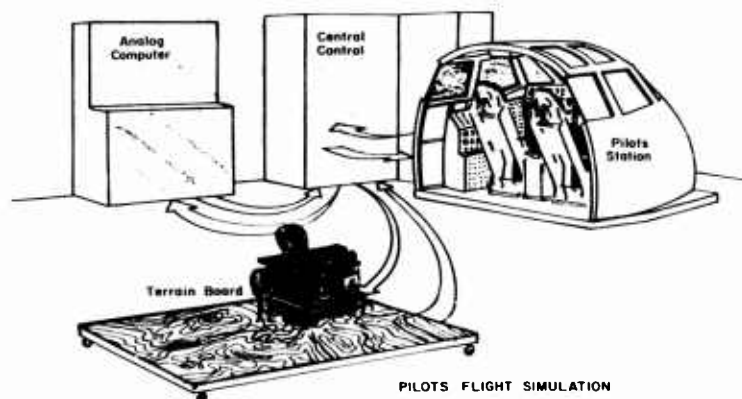


Figure 40-1. Boeing Flight Simulator Facility.

Motion Capabilities

The motion capabilities are those of the aircraft being simulated. A detailed discussion of the limits of the capabilities is not available.

Control System

The flight-control station of the pilot's station simulator provides a full-scale mock-up. Equipped with operable flight controls and instruments it is possible to combine the application of analog equipment, test conditions, and the human factors to produce controlled variations and measure results of operator performances under closely simulated flight conditions.

A control console provides a closed-loop simulation and allows monitoring of inputs of the test subject and system. Voice communication is also provided.

The PACE analog computer laboratory is located adjoining the simulator facility and it is an integral part of the real-time, closed-loop, flight control simulation facility.

Navigator's Simulator

Description

The navigation simulator was designed to investigate some of the problems associated with low-altitude radar interpretation. The simulator is equipped with the following instrumentation: Radar playback unit, tape recorder, manual navigation instruments, appropriate WAC and ONC charts, 35 mm. film strips consisting of pictures exposed at the rate of one frame per radar sweep, taken during several flight test missions, photographic enlargements and prints of film strips, and a Recordak projector.

Information

For information contact Human Factors Unit, Engineering Department, Boeing Airplane Company, Wichita 1, Kansas.

Bibliography

Boeing Wichita document entitled, "Flight Simulator Facility," No. D3-3662, March 1, 1961.

41. VARIABLE STABILITY RESEARCH AIRCRAFT (Cornell Aeronautical Laboratory)

Introduction

The Flight Research Department of Cornell Aeronautical Laboratory currently has three variable-stability aircraft capable of simulating the motions of a wide variety of aircraft in various flight conditions. The response characteristics to pilot inputs of these aircraft are variable in flight over wide ranges.

Each aircraft has been modified from its original configuration as regards its control system and the installation of special hydraulic and electronic systems. The first is a Douglas B-26, twin-engine, propeller-driven airplane; the second is a Lockheed F-94 jet fighter airplane; and the third is a T-33 jet trainer.

The research accomplished with these aircraft and other variable-stability aircraft not presently in existence has included evaluations to determine the effect on pilot opinion, and the ability of the pilot-airplane combination to accomplish specific tasks.

Motion Capabilities

In a simulation of an aircraft through the use of a variable-stability airplane, the evaluation pilot is, of course, in an aircraft in flight. This sense of actually being in an aircraft improves the simulation. Also, the cues of linear and angular accelerations and rates have approximately the proper phase relationships. All degrees of freedom of an aircraft are present, and the preciseness of the simulation depends entirely upon the accuracy with which the angular and linear responses are duplicated. In general, the variable stability aircraft will simulate the responses of airspeed, rate of change of airspeed, pitching velocity, and rolling acceleration to pilot-control inputs of ailerons and rudder.

The longitudinal characteristics normally consist of two oscillatory modes, short period and phugoid. In the T-33, the short-period natural frequency can be varied from approximately 1.5 cps. to values less than zero. The phugoid natural frequency can be varied from approximately 0.05 cps. to values less than zero.

As the pilot's control forces are obtained through feel servos, the stick force per stick displacement and hence the stick force per normal acceleration can also be varied. This range of variation is from 1.0 lb/g to infinity, with the minimum value dependent upon the short-period natural frequency.

The natural frequency of the Dutch roll mode can be varied from 1.0 cps. to less than zero. The damping ratio of this mode can be varied from 1.0 to 0.20. The roll-subsidence mode can be varied from a time-to-time amplitude of 0.05 to 10 seconds. The spiral mode can be varied from a time-to-half amplitude of 5.0 seconds to a time-to-double amplitude of 5.0 seconds.

The rolling velocity per aileron stick displacement can be varied from 0 to 150 degrees/sec/inch with a stick force per stick deflection variation from 250 lb/inch to 0.5 lb/inch. The values of sideslip and yawing velocity per pilot-rudder input are dependent upon the natural frequency of the Dutch roll mode.

Control System

The control system of the T-33 will be described in some detail. The control systems of the B-26 and F-94 are similar in concept; however, these two aircraft have only variable longitudinal stability and control characteristics. A special control system has been installed for a particular evaluation with the B-26 to determine the effects of spiral damping on instrument flying.

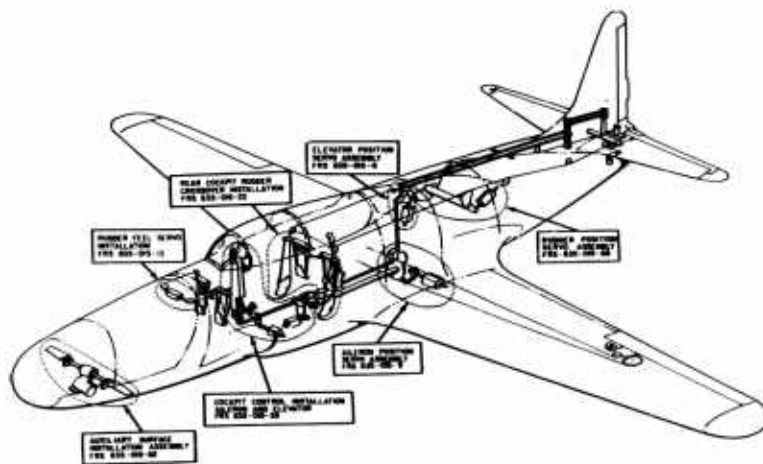


Figure 41-1. Variable Stability Aircraft (Cornell Aeronautical Laboratory): T-33A Modified Control System.

The elevator, aileron, and rudder controls in the front cockpit of the T-33 are disconnected from their respective control surfaces. They are connected instead to separate servo mechanisms for each control (See Figure 41-1). To perform basic research on flight controls, this "artificial-feel" system has been designed so that either a conventional stick or a wheel and column may be installed with equal facility. The elevator, aileron, and rudder surfaces each have separate servos permanently connected to them. A fourth set of control surfaces has been added to the nose of the airplane for simulation and evaluation of the phugoid or long-period longitudinal motion. The original nose has been replaced with a larger nose of an F-94 to provide the volume required for the electronic components of the automatic control system. Although most of the electronic components are installed in the nose, some are located in the cockpits, wheel wells, wings, plenum chamber, and tail surfaces. Finally, a number of circuits, controls, and switches related to normal airplane functions have been modified or relocated to make the airplane more fully a solo airplane from the rear seat. Thus, the rear pilot takes off and lands the airplane as a near-normal T-33. At test altitude, the safety pilot and the "evaluation" pilot perform the sequence of operations necessary to engage the automatic control system. When this procedure is completed, the evaluation pilot has command of the airplane through the artificial-feel controls.

Safety Features

Numerous fail-safe features have been incorporated in the design. In addition there are circuits which will automatically disengage the system if any of the control surface servo error signals exceeds a predetermined value or if either the normal or lateral acceleration of the airplane reaches preset limits. Finally, relief valves are connected across the surface servo pistons so as to limit the hinge moments which the automatically controlled surfaces can produce. Each pilot has two switches that will disengage the automatic control system, one on the control stick and one on the instrument panel. Whenever the system is disengaged for any reason, the safety pilot has control of the airplane immediately through the "normal" T-33 system.

Information

For information contact Mr. W. O. Breuhaus, Head of the Flight Research Department, Cornell Aeronautical Laboratory, Cornell University.

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3. Harper, R. P., "Flight Evaluations of Various Longitudinal Handling Qualities in a Variable Stability Jet Fighter," CAL Report No. TB-757-F-12, WADD TR 55-299, July 1955.
4. Chalk, C., "Additional Flight Evaluations of Various Longitudinal Handling Qualities in a Variable Stability Jet Fighter," CAL Report No. TB-1141-F-2, WADD TR 57-719, Part II, July 1958.
5. Beilman, Jr. and Harper, R., "Installation of an Automatic Control System in a T-33 Airplane for Variable Stability Flight Research, Part III; Ground and Flight Checkout," CAL Report No. TB-936-F-3, WADD TR 55-156, Part III, August 1957.

42. F-101 DYNAMIC RESEARCH AIRPLANE
(National Aeronautics and Space Administration,
Langley Research Center)

Introduction

An F-101A airplane has been outfitted by NASA, Langley Research Center, with equipment which makes it a versatile vehicle for performing flight research on a wide range of airborne automatic control systems and for simulating the stability and control characteristics of advanced aircraft.

Description

Included in the equipment installed in the airplane are analog and digital computers, a high performance control system capable of accepting electrical input signals, a stable platform, sensors for measuring airplane motions, control surface motions, and airplane flight conditions, a pilot's problem display, and a side-located pilot's flight controller.

The equipment that makes this research vehicle unique and which provides good versatility for airborne control-system and airplane-simulation studies is the on-board analog and digital computing system. The analog computer is used in much the same way as a conventional ground-based computer; that is, to build electrical analogies of systems and airplanes which it is desired to study. The digital computer complements the analog computer and one of its main uses is to solve geometry problems as, for example, in target simulation. A unique feature of the airborne computing system is that equipment is provided for converting analog signals to digital signals and digital signals to analog signals.

With the equipment installed in the F-101 airplane it is possible to simulate a wide variety of guidance systems including those for blind landing, homing, and bombing.

Control System

A very wide range of control-system configurations is within the capabilities of the simulator. Such systems range from fully

automatic to manual control with power boost. By use of the computer units, it is possible to simulate the stability and control characteristics of advanced aircraft.

Safety Features

A detailed description of the safety features is not available.

Information

For information contact Flight Research Division, NASA, Langley Research Center, Langley Field, Virginia.

43. F-104 JET REACTION CONTROL (National Aeronautics and Space Administration)

Introduction

An H_2O_2 jet reaction control system has been installed in an F-104 airplane to provide roll, pitch, and yaw control during high-altitude flights to low dynamic pressures. The controls are actuated by a three-axis side-located controller which operates electric servo-valves.

Description

(See Figure 43-1) A detailed description of the control system is not available.

Motion Capabilities

The rockets provide angular accelerations of 10 degrees/sec.² in roll and 5 degrees/sec.² in pitch and yaw. Some "Zero-G" flight experience will be obtained during the reaction-control program. Maximum duration at "Zero-G" is expected to be about 50 seconds.

Control System

The present control system is open-loop, but it is planned to incorporate closed-loop.



Figure 43-1. NASA's F-104 Jet Reaction Control System.

44. X-15

(USAF, National Aeronautics and Space Administration)

Introduction

An H_2O_2 jet reaction control system has been installed in the X-15 airplane to be used during flights producing low dynamic pressure.

Description

A detailed description of the control system is not available.

Motion Capabilities

The rockets, operated by a mechanical control-valve system connected to a three-axis left-hand operated controller, provide angular accelerations of 10 degrees/sec.² in roll and 5 degrees/sec.² in pitch and yaw. Flight duration of 200 seconds at low dynamic pressures are available. These flights also provide appreciable test duration at "Zero-G," with the maximum duration depending upon the maximum altitude capability. It appears that test durations of 300 seconds at "Zero-G" may be feasible.

MOTION DEVICES

A Summary Chart

	SUB-CLASSIFICATION	TYPE OF MACHINE	VEHICLE'S PRIMARY PURPOSE	MAXIMUM ACCELERATION	MAXIMUM VELOCITY OR FREQUENCY RANGE	MAXIMUM DISPLACEMENT OR AMPLITUDE	CONTROL SYSTEM	SAFETY FEATURES
OSCILLATORY DEVICES	Vibration in a Vertical Line	Vertical Accelerator 1	Biodynamic Physiological Performance	±3 G	0-10 Cps.	±10 Ft.	Open Loop Closed Loop Proposed	Electronic Limiters
		NAA Dynamic Flight Simulator 3	Flight Control Tests	22 G	9.0 Ft/Sec.	±5.5 Ft. Vertical	Open or Closed Loop	Relief Valve Electronic L
		Large Displacement-Amplitude Vibration Machine 4	Biodynamic Physiological Performance	15 G	2.2-50 Cps.	±2 In. Vertical	Open Loop	Clutch
		Shake Table of the Naval Human Centrifuge 19	Biodynamic Physiological Performance	5 G	10 Cps.	4 Ft. Excursion		
	Vibration in a Longitudinal Line	Vibrator of the Wyle Omni-Environmental Simulator 22	Rocket Launch Simulation	4,000 Lbs. Force	2,000 Cps.			
		High-Amplitude Vibration Machine 6	Biodynamic Physiological Performance	20 G	2-30 Cps.	9 In. Excursion	Electric Frequency Control	Regenerative Braking Circuit
	Vibration in Both a Vertical and Longitudinal Line	Shake Table of the Vertical Accelerator (WADD) 1	Biodynamic Physiological Performance		10-20 Cps.	0.12 In.		
		USAMRL Vibrator 2	Biodynamic Physiological Performance	10 G/300 Lbs. Load 20 G/100 Lbs. Load	5-2,000 Cps.	0.5 In.	Open Loop	
		Carriage of the "Heaver" 17	Physiological (Vestibular) Performance	20 G Vertical	1-15 Cps.	40 Ft. Vertical 2-3 Ft. Lateral	Closed Loop	Emergency Br
		Vibration Machine (Platform for the Equilibrium Chair) 14	Biodynamic Physiological Performance	10 G	60 Cps.	0.25 In.	Mechanically Adjusted	Safety Switch
	Rotation in a Horizontal Plane and in One Vertical Plane	Chair of the Equilibrium Chair Assembly 14	Physiological (Vestibular) Performance		40°/Sec.	±20° Pitch and Roll	Closed Loop	
		Pitch-Roll Chair 8	Vehicle Re-entry Simulation	15 Rad/Sec ² Roll 10 Rad/Sec ² Pitch	8 Rad/Sec. Roll 2 Rad/Sec. Pitch	±1080° Roll -15° to +40° Pitch	Closed Loop	Emergency Stop
		Pitch-Roll Simulator 9	Flight Simulation		60° Sec. Pitch and Roll		Closed Loop	
		Horizon Projector 38	Flight Simulation		3 Rad/Sec. Roll and Yaw		Closed Loop	Mechanical Stop
	Rotation in Three Planes	Iron Cross 11	Physiological Performance Tests	Motion Capabilities are a Function of the Control System		±25° Roll ±20° Pitch ±160° Yaw	Open or Closed Loop	
		Three-Degree-of-Freedom Motion Simulator 12	Physiological Performance Tests	18 Rad/Sec ² Roll 6 Rad/Sec ² Pitch and Yaw	8 Rad/Sec. Roll 2 Rad/Sec. Pitch and Yaw	±360° Roll 145° Pitch and Yaw	Closed Loop	Emergency Stop
		Gondola of the "Heaver" 17	Physiological (Vestibular) Performance	10 Rad/Sec ² Roll, Pitch, and Yaw	10 Rad/Sec.	Continuous Pitch, Roll, and Yaw Rotation	Closed Loop	
		Gondola of the "Omni-flyer" (Versions: 1, 2, and 3) 21	Physiological Performance Tests	20 Rad/Sec ² 50 G Impact		Continuous Pitch, Roll, and Yaw Rotation	Closed Loop	
	Linear Vibration and Rotation Combined	Capsule of the Catapult and Arrest Acceleration Simulator 37	Physiological Performance Tests			2 Ft. Vertical ±30° Pitch	Open Loop Vertical Motion	Hydraulic Brakes
		NAP Simulator by Langley Research Center 13	Aircraft Simulation	4.5 G	5 Ft/Sec. Vertical	8 Ft. Vertical 14° Pitch	Closed Loop	
		Equilibrium Chair Assembly (Chair and Vibrator) 14	Physiological (Vestibular) Performance					
		Wyle Omni-Environmental Simulator (Arm and Vibrator) 22	Rocket Launch Response					
		Bell Helicopter Flight Simulator 16	Flight Simulation	40°/Sec ² Roll 250°/Sec ² Pitch 150°/Sec ² Yaw 0.3 G Vertical	5-60 Cps. Vibration 1 Rad/Sec. Platform Rotation	±10° Roll ±80° Pitch ±10° Yaw ±1 Ft. Vertical	Closed Loop	Electronic Limits Allowable Over-travel
		Grumman Motion Simulator 10	Flight Simulation	5.2 Rad/Sec ² Roll 7.6 Rad/Sec ² Pitch 1 G Yaw	1.6 Rad/Sec. Roll 0.8 Rad/Sec. Pitch 5.1 Ft/Sec. Yaw	±30° Roll ±15° Pitch 6 Ft. Vertical	Open or Closed Loop	Automatic Computer Reset Device
		"Heaver" (Gondola and Carriage) 17	Physiological (Vestibular) Performance				Closed Loop	
		Sustained Acceleration and Linear Vibration 18	Physiological Performance	1/4 G to 1 G	5.5-12 Cps.	±0.75 In.		
	Sustained Acceleration, Linear Vibration, and Rotation	Dynamic Escape Simulator 20	Vestibular Function Studies	Main Axis: 10-12 G/Sec. Cab Axis: 5-10 Rad/Sec ² Fork Axis: 20 Rad/Sec ²		Continuous Pitch, Roll, and Yaw Rotation		
		"Omni-flyer", Versions: 1, 2 and 3 (Gondola and Gimbals) 21	Rocket Launch Simulation	50 G		±60 Ft. Vertical (Versions 1 and 2) ±80 Ft. Diagonally for all Versions		

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OSCILLATORY DEVICES									
Rotation in a Horizontal Plane and in One Vertical Plane	Equilibrium Chair Assembly	(Vestibular) Performance							
	Pitch-Roll Chair	Vehicle Re-entry Simulation	15 Rad/Sec ² Roll 10 Rad/Sec ² Pitch	8 Rad/Sec. Roll 2 Rad/Sec. Pitch	±1080° Roll -15° to +40° Pitch	Closed Loop	Emergency Stop		
	Pitch-Roll Simulator	Flight Simulation		600 Sec. Pitch and Roll		Closed Loop			
	Horizon Projector	Flight Simulation		3 Rad/Sec. Roll and Yaw		Closed Loop	Mechanical Stop		
Rotation in Three Planes	Iron Cross	Physiological Performance Tests	Motion Capabilities are a Function of the Control System		±250° Roll ±200° Pitch ±360° Yaw	Open or Closed Loop			
	Three-Degree-of-Freedom Motion Simulator	Physiological Performance Tests	18 Rad/Sec ² Roll 6 Rad/Sec ² Pitch and Yaw	8 Rad/Sec. Roll 2 Rad/Sec. Pitch and Yaw	±360° Roll ±450° Pitch and Yaw	Closed Loop	Emergency Stop		
	Gondola of the "Heaver"	Physiological (Vestibular) Performance	10 Rad/Sec ² Roll, Pitch, and Yaw	10 Rad/Sec.	Continuous Pitch, Roll, and Yaw Rotation	Closed Loop			
	Gondola of the "Omniflyer" (Versions: 1, 2, and 3)	Physiological Performance Tests	20 Rad/Sec ² 50 G Impact		Continuous Pitch, Roll, and Yaw Rotation	Closed Loop			15,000 Lbs.
Linear Vibration and Rotation Combined	Capsule of the Catapult and Arrest Acceleration Simulator	Physiological Performance Tests			2 Ft. Vertical ±30° Pitch	Open Loop Vertical Motion	Hydraulic Brakes	300 Lbs.	
	NAP Simulator by Langley Research Center	Aircraft Simulation	4.5 G	5 Ft/Sec. Vertical	8 Ft. Vertical ±40° Pitch	Closed Loop			
	Equilibrium Chair Assembly (Chair and Vibrator)	Physiological (Vestibular) Performance							
	Wyle Omni-Environmental Simulator (Arm and Vibrator)	Rocket Launch Response							
	Bell Helicopter Flight Simulator	Flight Simulation	400/Sec ² Roll 250/Sec ² Pitch 150/Sec ² Yaw 0.3 G Vertical	5-60 Cps. Vibration 1 Rad/Sec. Platform Rotation	±100° Roll ±80° Pitch ±100° Yaw 3 Ft. Vertical	Closed Loop	Electronic Limiters Allowable Over-travel	1,000 Lbs.	
	Grumman Motion Simulator	Flight Simulation	5.2 Rad/Sec ² Roll 2.6 Rad/Sec ² Pitch 3 G Yaw	1.6 Rad/Sec. Roll 0.8 Rad/Sec. Pitch 5.1 Ft/Sec. Yaw	±300° Roll ±150° Pitch 6 Ft. Vertical	Open or Closed Loop	Automatic Computer Reset Device	1,000 Lbs.	
	"Heaver" (Gondola and Carriage)	Physiological (Vestibular) Performance				Closed Loop			5,000 Lbs. Pa
	Shake Table (Mounted on Centrifuge)	Physiological Performance	1/4 G to 1 G	5.5-12 Cps.	±0.75 In.				
Sustained Acceleration and Linear Vibration	Dynamic Escape Simulator	Vestibular Function Studies	Main Axis: 10-12 G/Sec. Cab Axis: 5-10 Rad/Sec ² Fork Axis: 20 Rad/Sec ²		Continuous Pitch, Roll, and Yaw Rotation				1,000 Lbs. Pa
	"Omniflyer", Versions: 1, 2 and 3 (Gondola and Gimbals)	Rocket Launch Simulation	50 G		360 Ft. Vertical (Versions 1 and 2) 180 Ft. Diagonally for all Versions				15,000 Lbs.
	Naval Human Centrifuge (Arm, Shake Table, Inner-Outer Gimbals)	Flight Simulation				Closed Loop			
IMPACT OR ABRUPT LINEAR ACCELERATORS	Grumman Vertical Drop Tower	Seats and Electronic Gear Tests	40,000 lbs. Impact Force	4,000,000 lbs./Sec. Rate of Application	50 Ft.	Open Loop	Hydraulic Brakes and Steel Straps	700 lbs. Cart Weight	
	WADD Deceleration Tower	Crash Research Studies	5 G at 150 G/Sec. to 50 G at 5,000 G/Sec.		50 Ft.	Open Loop	Allowable Distance for Overruns	400 lbs.	
	Hyge Shock Tester	Physiological Performance (Small Animals)	30 G Impact			Open Loop	Metering Pin Cylinder Acts as a Brake	140 lbs.	
	ACEL Ejection Seat Tower	Emergency Escape Systems Tests	20 G	100 Ft/Sec.	145 Ft.	Manually Operated	Arresting Pawls		
	"Pile Driver"	Physiological Performance Tests	10 G to 1,000 G		540 Ft.	Open Loop	Allowable Distance for Overruns	5,000 lbs.	
	Naval Ordnance Track	Catapult Launching Tests	10 G	1,000 Ft/Sec.	4.1 Mi.	Manually Initiated	Hydraulic Brakes	20,000 lbs.	
	HG-1 Linear Accelerator	Crash Tests	43 G	140 Ft/Sec.	380 Ft.	Manually Initiated	Steel Cage for Protection		
	Daisy Track	Biodynamic Physiological Equipment Tests	200 G	175 Ft/Sec.	120 Ft.	Manual			500 lbs. to 200
	Sled of the Catapult and Arrest Acceleration Simulator	Physiological Performance Tests	15 G	210 Knots	500 Ft. Horizontal	Closed Loop for Horizontal Motion	Hydraulic Brakes	300 lbs.	

Test Name	Roll	Pitch	Yaw	Control System	Emergency Stop	Weight	Acceleration	Altitude	Year	Location
Entry	15 Rad/Sec ² Roll	10 Rad/Sec ² Pitch	8 Rad/Sec. Roll	2 Rad/Sec. Pitch	±1080° Roll	-15° to + 40° Pitch	Closed Loop	Emergency Stop		Ames Research Center Moffett Field, Calif.
Simulation			60° Sec. Pitch and Roll		Closed Loop				1959	Langley Research Center
Simulation			3 Rad/Sec. Roll and Yaw		Closed Loop	Mechanical Stop			1959	Ames Research Center Moffett Field, Calif.
Calibration Tests	Motion Capabilities are a Function of the Control System				±25° Roll ±20° Pitch ±360° Yaw	Open or Closed Loop				
Calibration Tests	18 Rad/Sec ² Roll 6 Rad/Sec ² Pitch and Yaw	8 Rad/Sec. Roll 2 Rad/Sec. Pitch and Yaw			±360° Roll ±45° Pitch and Yaw	Closed Loop	Emergency Stop		1960	Ames Research Center Moffett Field, Calif.
Calibration Tests	10 Rad/Sec ² Roll, Pitch, and Yaw	10 Rad/Sec.			Continuous Pitch, Roll, and Yaw Rotation	Closed Loop			Proposed	Naval Air Development Center Johnsville, Pa.
Calibration Tests	20 Rad/Sec ² 50 G Impact				Continuous Pitch, Roll, and Yaw Rotation	Closed Loop		15,000 Lbs.	Proposed	Naval Air Development Center Johnsville, Pa.
Calibration Tests					2 Ft. Vertical ±30° Pitch	Open Loop Vertical Motion	Hydraulic Brakes	300 Lbs.	100 G/Sec.	Dupont Airport Wilmington, Delaware
Simulation	4.5 G	5 Ft/Sec. Vertical	8 Ft. Vertical ±40° Pitch	Closed Loop					1959	Langley Research Center
Calibration Tests										Wright Air Development Division Dayton, Ohio
Launch										Wyle Laboratory El Segundo, Calif.
Simulation	40°/Sec ² Roll 25°/Sec ² Pitch 15°/Sec ² Yaw 0.3 G Vertical	5-60 Cps. Vibration 1 Rad/Sec. Platform Rotation	±10° Roll ±8° Pitch ±10° Yaw 3 Ft. Vertical	Closed Loop	Electronic Limiters Allowable Over-travel	1,000 Lbs.			1959	Bell Helicopter Corp. Fort Worth-Dallas Texas
Simulation	5.2 Rad/Sec ² Roll 2.6 Rad/Sec ² Pitch 3 G Yaw	1.6 Rad/Sec. Roll 0.8 Rad/Sec. Pitch 5.1 Ft/Sec. Yaw	±30° Roll ±15° Pitch 6 Ft. Vertical	Open or Closed Loop	Automatic Computer Reset Device	1,000 Lbs.			1959	Grumman Aircraft Corp., Bethpage, N. Y.
Calibration Tests				Closed Loop		5,000 Lbs. Payload			Proposed	Naval Air Development Center Johnsville, Pa.
Calibration Tests	1/4 G to 1 G	5.5-12 Cps.	±0.75 In.							Wright Air Development Division Dayton, Ohio
Function	Main Axis: 10-12 G/Sec. Cab Axis: 5-10 Rad/Sec ² Fork Axis: 20 Rad/Sec ²				Continuous Pitch, Roll, and Yaw Rotation			1,000 Lbs. Payload		Wright Air Development Division Dayton, Ohio
Launch	50 G		360 Ft. Vertical (Versions 1 and 2) 180 Ft. Diagonally for all Versions			15,000 Lbs.			Proposed	Naval Air Development Center Johnsville, Pa.
Simulation				Closed Loop					Proposed	Naval Air Development Center Johnsville, Pa.
Electronic	40,000 Lbs. Impact Force	4,000,000 Lbs./Sec. Rate of Application	50 Ft.	Open Loop	Hydraulic Brakes and Steel Straps	700 Lbs. Cart Weight	Function of Brake Pressure		1959	Grumman Aircraft Corp., Bethpage, N. Y.
Research Studies	5 G at 150 G/Sec. to 50 G at 5,000 G/Sec.		50 Ft.	Open Loop	Allowable Distance for Overruns	400 Lbs.	150 G/Sec. at 50 5,000 G/Sec. at 50G			Wright Air Development Division Dayton, Ohio
Calibration Tests (male)	30 G Impact			Open Loop	Metering Pin Cylinder Acts as a Brake	140 Lbs.				Wright Air Development Division Dayton, Ohio
Escape Tests	20 G	100 Ft/Sec.	145 Ft.	Manually Operated	Arresting Pawls		250 G/Sec.		1959	Namaten Naval Base Philadelphia, Pa.
Calibration Tests	10 G to 1,000 G		540 Ft.	Open Loop	Allowable Distance for Overruns	5,000 Lbs.			Proposed	Naval Air Development Center Johnsville, Pa.
Launching	10 G	1,000 Ft/Sec.	4.1 Mi.	Manually Initiated	Hydraulic Brakes	20,000 Lbs.				China Lake, Calif.
Tests	43 G	140 Ft/Sec.	380 Ft.	Manually Initiated	Steel Cage for Protection		1,075 G/Sec.		1946	Namaten Naval Base Philadelphia, Pa.
Calibration Tests	200 G	175 Ft/Sec.	120 Ft.	Manual		500 Lbs. to 200 G	12,000 G/Sec.			Air Force Missile Development Center Holloman AFB, N. Mex.
Calibration Tests	15 G	210 Knots	500 Ft. Horizontal	Closed Loop for Horizontal Motion	Hydraulic Brakes	300 Lbs.	100 G/Sec.			Dupont Airport Wilmington, Delaware

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